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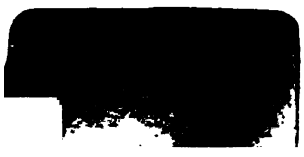

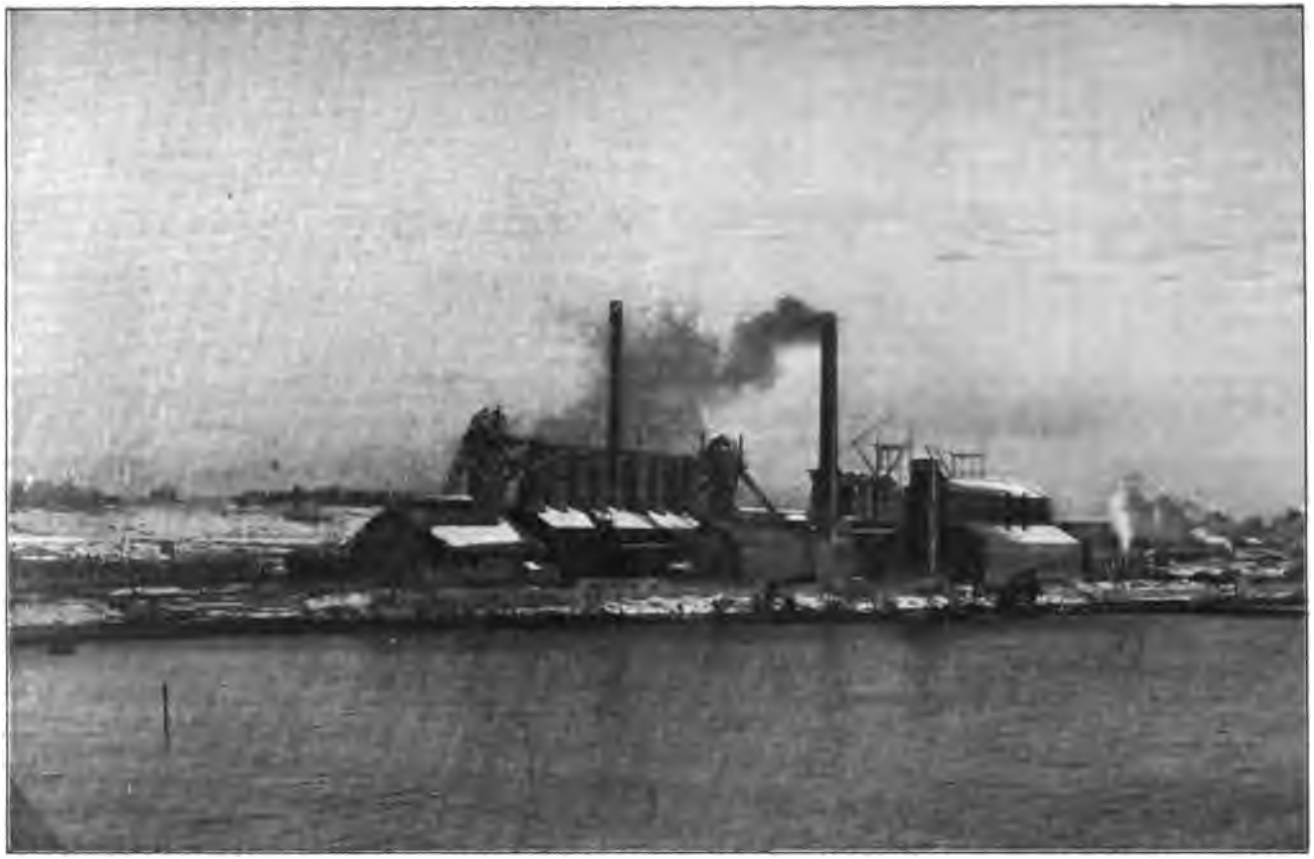

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VOLUME V.

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AMERICAN SCHOOL of CORRESPONDENCE at ARMOUR INSTITUTE of TECHNOLOGY

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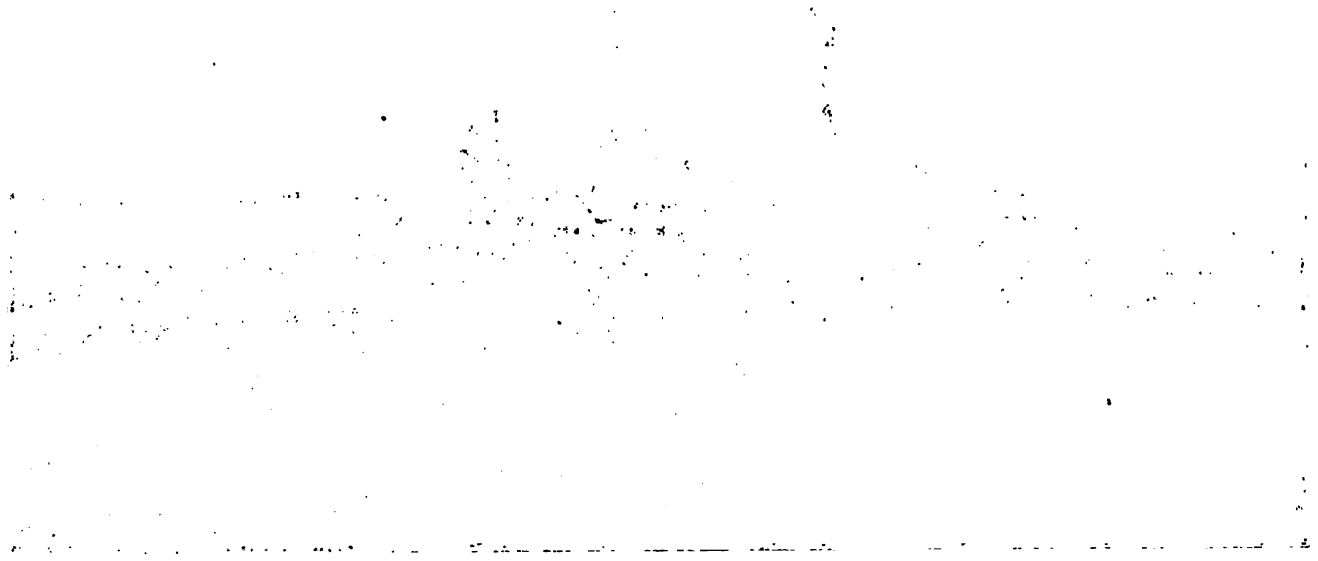

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AMERICAN SCHOOL of CORRESPONDENCE at ARMOUR INSTITUTE of TECHNOLOGY

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TABLE OF CONTENTS

VOLUME V.

CHEMISTRY METALLURGY
THE STEAM ENGINE: Parts I and II
STEAM ENGINE INDICATORS VALVE GEARS
AUTOMOBILES

Chemistry

	Page
Early History	3
Fundamental Principles:	4
Physical and Chemical Changes	4
Molecules and Atoms	4
Elements:	5
Table of Symbols	7
Atomic Weights:	9
Vapor Density	10
Molecular Weight	11
Chemical Affinity:	12
Union by Weight:	13
Law of Conservation of Matter	13
Law of Definite Weight	13
Valence	14
Equations	17
Solution:	20
Saturated Solution	21
Precipitate	21
Oxygen:	22
Physical and Chemical Properties, Compounds, Uses and Preparation	22
Hydrogen:	
Physical and Chemical Properties, Compounds, Uses and Preparation	24
Water:	
Occurrence and Properties	26
Hard and Soft Water	28
Distillation	29
Nitrogen:	
Ammonia:	30
Physical and Chemical Properties, Compounds, Uses and Preparation	30
Atmosphere:	
Constituents	31
Argon	31
Humidity	32
Carbon:	
Occurrence	34
Amorphous:	35
Charcoal, Lampblack, Coke and Coal	36
Graphite	37
Diamond	37
Miscellaneous Forms	38
Uses and Compounds	38
Illuminating Gas:	
Water Gas	40
Coal Gas	40
Combustion:	
General Principles	42
Carbon Dioxide	43
Carbon Monoxide	45
Amount of Air Required for Combustion:	46
Products of Combustion	47
Heat of Combustion	49
Evaporation per Pound of Fuel	50
Temperatures of Combustion:	51
Latent and Specific Heat	52
British Thermal Units	53
Table of Specific Heat	53
Steam Tables	62

Metallurgy

	Page
Iron	3
Ores:	
Magnetite	3
Hematite	3
Limonite	3
Siderite	5
Minerals:	
Iron Pyrites	5
Frankilnite	5
Limestone	5
Dolomite	5
Preparation of Ores	5
The Blast Furnace:	
Detail Parts	6
Materials of Blast Furnace:	
Ores, Fluxes and Fuels	7
Operation of Furnace:	
Blowing In	7
Output of Furnace	8
Banking the Furnace	8
Chemistry of Furnace:	9
Slag	9
Stoves	9
Cast Iron:	
Tensile Strength	10
Grades of Cast Iron	10
Influence of Carbon, Silicon, Phosphorus, Sulphur and Manganese	11
Castings	12
Malleable Cast Iron	12
Wrought Iron:	
Direct Processes:	
Catalan Process	13
Puddling Process:	
Utilizing WasteGases	15
Dank's Puddling Furnace	15
Welding	17
Steel:	
Cementation Process:	17
Blister Steel	17
Shear Steel	17
Composition of Various Heats—"Spring," "Country," etc.	18
Crucible Process:	19
Materials	19
American Practice	19
Grades of Steel	19
Bessemer Process:	
Converter:	21
Types of Converter	21
Acid Bessemer	21
Basic Bessemer	21
Cupola Process	22
Direct Process:	
Blowing	22
Spiegel	23
Ferro-manganese	24
Moulds	25
Ingots:	
Method of Pouring	25
Shape of Ingots	26
Rail Making:	27
Soaking Pit	27
Blooming Mill	27
Open-hearth Process:	
Martin Process	28
Siemens Process	28
Combination Process:	
Acid Process	29
Basic Process	29
Management of Acid Process	30
Management of Basic Process	31
Gas Producers:	
Siemens Producer	31
Wellman Producer	32
Taylor Producer	32
Special Steels	32
Casehardening	34
The Harvey Process	34
Effects of Elements in Steel:	
Carbon	35
Silicon, etc.	35
Tempering:	
Heat at Different Colors	36
Copper:	
Ores	37
Extraction	37
Cupola Smelting	38
Refining:	39
Electric Refining	40
Properties of Copper	41
Lead:	
Lead Ores	41

	Page
Smelting	42
Smelting Furnace	42
Softening and Desilverizing	43
Recovery of Silver and Gold	44
Refining	44
Properties of Lead	45
Tin	45
Zinc	46
Aluminum:	47
Table of Metals	49
Alloys	50

The Steam Engine

Early Forms	3
Savery's Engine	3
Pulsometer	4
Newcomen's Engine	5
Watt's Engine	8
Stephenson's "Rocket" Locomotive	9
Woolf's Engine	10
Detail Parts of Steam Engine:	
Cylinder	11
Cylinder Head	11
Piston Rod	12
Tail Rod	12
Crosshead	13
Connecting Rod	13
Crank Pin	13
Crank	13
Shaft	13
Frame	13
Steam Chest	13
Eccentric	13
Slide Valve	14
Types of Engines:	
Classification	15
Simple Engines	16
Compound Engines	17
Triple Expansion	19
Quadruple Expansion	19
High-speed Engines	21
Westinghouse Single-acting	24
Marine Engines	27
Locomotive Engines	28
Pumping Engines	30
Direct-acting Steam Pumps	31
Duplex Steam Pumps	34
Corliss Engine	34
Condensers:	
Surface Condensers	37
Jet Condensers	40
Cooling Towers	43
Fly Wheel:	45
Diagrams of Turning Moment	47
Calculation of Weight	50
Governors:	52
Pendulum Governor	54
Formulæ	54
Porter Governor	57
Formulæ	58
Spring Governor	59
Shaft Governor	59
Buckeye Engine Governor	60
Straight-line Engine Governor	61
Lubrication:	62
Liquid Lubricants	64
Solid Lubricants	64
Sight Feed Lubricator	66
Steam Turbine:	68
De Leval Steam Turbine	69
Parsons' Turbine	73

Steam Engine Indicators

Preliminary Definitions	3
Explanation of Indicator Diagrams:	4
Mean Effective Pressure	6
Mean Ordinate	6
Watt's Diagram of Work	8
Watt's Indicator	9
Modern Indicators:	9
The Thompson Indicator	10
The Crosby Indicator	12
The Tabor Indicator	15
Reducing Motions:	18
Pantograph	19
Brumbo Pulley	20
Taking Indicator Diagrams	22
Value of Diagrams:	23
Horse-power:	23

	Page
Formula for Horse-power	24
Calculation for H. P. for Both Ends of Cylinder	25
Steam Engine Constants:	26
Piston Speed	26
Mean Effective Pressure	26
Table of Constants	27
Brake Horse-power:	28
The Prony Brake	28
The Rope Brake	29
Formulæ	29
Mechanical Efficiency	31
Measuring Area of Card:	31
By Ordinates	31
By Planimeter:	33
Directions for use of Planimeter	34
Thermal Efficiency	35
Ideal Indicator Card:	35
Events of the Stroke	36
Comparison of Ideal and Actual Cards	37
Drawing Ideal Card:	39
Hyperbolic Curve	39
Cards for Compound Engines	40
Woolf Type:	
Theoretical Card	40
Actual Card	41
Cross Compound Type:	
Theoretical Card	42
Actual Card	44
Combined Cards:	
For Compound Engines	45
For Triple and Quadruple Expansion Engines	46
Faults of Indicator Cards:	48
Causes and Remedies	49
Calculation of Steam Consumption:	52
Formulæ	55

Valve Gears

	Page
Classification of Engines	3
Slide Valve:	3
Detail Parts:	
Valve Seat	4
Port	4
Bridges	4
Inside and Outside Lap	4
Eccentric:	
Detail Parts and Definitions	5
Operation and Adjustment of Valve	5
Valve without Lap	5
Valve with Lead and Lap:	7
Angle of Lead	8
Table of Valve Adjustments	12
Definitions of Detail Parts and Positions	12
Valve Diagrams	15
Zeuner Valve Diagrams	20
Problems of Design	23
Design of Slide Valve:	
Area of Pipe	29
Width of Port (Steam)	30
Width of Port (Exhaust)	31
Lead, Cut-off, etc.	31
Designing Slide Valve and Valve Seat	32
Valve Setting:	
Putting on Center	35
Equal Lead	36
Equal Cut-off	36
Reversing Gear:	
Stephenson Motion	38
Open and Crossed Rods	40
Gooch Link	41
Allen Link	41
Joy Valve Gear	42
Modifications of Slide Valve:	
Piston Valve	44
Double-ported Valve	45
Trick Valve	46
Balanced Valve	47
Double Valve Gears:	
Meyer	48
Corliss:	49
Setting Corliss Valves	53

The Steam Engine: Part II.

	Page
Action of Heat:	3
Melting and Boiling Points	5

	Page
Mechanical Equivalent	6
Expansion of Gases:	7
Boyle's Law	7
Law of Charles	8
Saturated Vapor:	10
Formulæ	11
Steam Tables	14
Superheated Vapor	18
The Steam Engine:	
Theoretical Engine	20
Formulæ	24
Actual Engine	22
Efficiency	22
Losses in Engine	23
Multiple Expansion	26
Jacketing	30
Superheated Steam	32
Condensers:	34
Advantages	35
Cooling Surface	38
Measurement of Vacuum	39
Corliss Valves	51
Piston Speed	41
Ratio of Expansion	42
Work in Cylinder	43
Crank Action	45
Economy of Engine	48
Testing Engines:	53
Thermometers	54
Indicators	55
Scales	55
Water Meters	55

Automobiles.

	Page
Early History:	3
Hero or Reaction Engine	3
Cugnot's Automobile	3
Trevethick's Automobile	5
James' Automobile	6
Hancock's Steam Omnibus	6
Russell's Automobile	6
Development of Traction Engines	7
Prize Trial Instituted by the "Engineer" of London	7
Trial at Paris for Heavy Weight Vehicles	8
Panhard Omnibus	9
Trial at Liverpool for Heavy Motor Wagons	9
Details of the Automobile:	10
Motor	10
Gas Engine	10
Storage Battery	10
Gasoline	11
Acetylene	11
Economy	12
Light Weight	12
Development of the Internal Combustion Motor	13
Advantages and Disadvantages of Electric Automobiles	14
Method of Wiring Battery for Speed Changes	15
Didier Method of Changing Speed	17
Tires:	18
Iron	19
Hard or Solid Rubber	19
Pneumatic	19
Steering Gear	20
Brake:	21
Renault	21
Description of Adams Express Co.'s Automobile:	25
Details of Construction	25
Automobiles for Farming Purposes	26
Automobiles for Military Purposes:	28
Advantages	28
Racing Automobile	30
Automobile Records	31
Speed Regulation	31

Volume V.

MARINE AND LOCOMOTIVE
BOILERS AND ENGINES
AIR BRAKES

SECTION I.

CHEMISTRY.

Chemistry is the science which treats of matter in its simplest forms, and the combinations of these forms which make up all material substances.

All animal and vegetable matter, and the solid rock and earthy substances which make up the earth's crust, undergo their changes according to chemical laws. The same is true of water and all other liquids, and of air and gases.

Thus we see that Chemistry relates to an enormous number of substances. The number of the various kinds of substances which exist on the earth is so great that they have never even been counted. Probably there are many substances in the common every-day things of life that have not yet been recognized by the most skilful chemists. However, many compounds have been described, and the chemical laws now known are of great value in finding out the composition of various substances.

The rudiments of Chemistry may be traced back to the ancient Egytians. The Arabs and Greeks sought to change metals into gold and searched for a liquid which would cure all ills and confer the blessing of perpetual life. These experimenters were called **Alchemists.**

During the second period in the history of Chemistry, chemical changes were said to be caused by a substance called **Phlogiston.** This substance was thought to be contained in all combustible matter, and the theory that fire showed the escape of phlogiston was upheld by the most learned chemists of the time.

The phlogiston theory was given up when Lavoisier, a French chemist, demonstrated his theories of combustion and chemical union. On account of his important experiments and discoveries, he is called the "father of Chemistry." Lavoiser proved that when combustible substances are burned, they combine with a gas called oxygen, forming new substances.

PHYSICAL AND CHEMICAL CHANGES.

The various substances with which we are familiar frequently undergo changes. It is important to know whether the change is physical or chemical. If the change is physical, the substance has the same essential properties as before the change. Chemical changes affect the nature of the substance and the new forms may have entirely different properties.

Sugar may be crushed into fine particles yet the small particles retain the sweet taste, white color and crystalline structure. This change is **physical** because the particles have been merely broken up and each fine particle retains the properties of a considerable quantity.

Suppose sugar is mixed with iron filings. The mixture is sweet and by means of a magnet the iron filings can be separated from the sugar and both substances be of the same state and condition as before. This change is physical but is usually called a mechanical mixture. If two or more substances are mixed together, and the resulting substance has the properties of the constituents, it is called a *mechanical mixture.*

Suppose we apply heat to the sugar, or pour sulphuric acid onto ordinary granulated sugar. The substances formed have different properties. Instead of white sugar, a black substance is formed which resembles charcoal. As the properties of this black substance are different from those of sugar, we say that the change is **chemical.**

MOLECULES AND ATOMS.

A small lump of sugar can be crushed or broken so as to form many smaller lumps, and these small lumps further divided into others still smaller. The lumps may be divided into such small particles that they cannot be seen, yet they possess the properties of sugar. Let us suppose this division is continued indefinitely. There will be a *smallest* particle of sugar. Or, there is a point where further sub-division by mechanical means is impossible. This smallest particle, called a molecule, can be subdivided only by chemical means, and the chemical agents cause new forms of matter. As the small particles, or molecule, cannot

be divided by mechanical means, we say that a molecule is the smallest particle which exists alone and retains most of the properties of a considerable quantity of the substance. A **molecule** may be defined as being *the smallest quantity of matter that can exist by itself.*

The molecule can be divided by chemical means, but the particles thus formed, called atoms, cannot be further divided even chemically after a certain stage is reached. Thus, theoretically, pure sugar can be divided mechanically into molecules, and the molecules divided chemically into three forms of matter which cannot be further divided by any known means. These three substances are carbon (a solid at ordinary temperature), oxygen, (a gas at ordinary temperature), and hydrogen (a gas at ordinary temperature). Since these are the simplest forms and cannot be broken up, they are final divisions. Atoms generally do not exist separately or uncombined, the molecule being the smallest particle which exists alone. *An atom is the smallest particle of a substance that can exist, not alone, but combined with other atoms forming molecules.*

Briefly, we may say that an atom is very small and indivisible, either by physical or chemical means. It has a definite weight. All the atoms of an element are of the same weight. The atoms of a substance have an attraction for atoms of other substances.

A molecule is a group of atoms held together by the attractive force which they have for each other. The molecule can be divided by chemical agents into atoms. The molecules of a given substance always contain the same numbers and the same kinds of atoms.

ELEMENTS.

We know that sugar is broken up by sulphuric acid and the substances obtained have none of the characteristics of sugar. Two new substances were formed, carbon (or charcoal) and water. The water can be broken up into two gases, but the carbon cannot be divided so that new substances are formed. In other words, if carbon is divided or broken up, nothing but carbon is obtained.

The chemist can take carbon out of sugar, but he cannot take anything but carbon out of carbon. He can take oxygen out of sugar, but he cannot take anything but oxygen out of oxygen.

The science of Chemistry shows that all substances are made up of various combinations of simple forms of matter, which cannot, by any known means, be divided into other kinds of matter. Thus, sugar is a compound or combination of simple forms, and the simple forms carbon, oxygen, and hydrogen are called **elements.**

An element may be defined as being *a form of matter which chemists have not yet been able to break up into other forms of matter.*

The thousands of words in the English language are made up of combinations of letters of which there are less than thirty. The letters are the simple forms, or elements, and the words are the combinations, or substances. The millions of substances found on the earth are made up of various combinations of about seventy elements. The exact number of elements is not known, and new ones are being discovered from time to time.

The table on the opposite page gives a partial list of elements, their symbols or abbreviations, their atomic weights, their physical conditions at ordinary temperature and their specific gravities.

A large proportion of the elements are uncommon. Carbon, copper, gold, iron, lead, mercury, nickel, phosphorus, silver, suphur, tin, zinc, oxygen and nitrogen are almost the only ones that are familiar to most people.

Almost all of the elements exist in very small quantities. It has been estimated that an amount equal to ninety-nine one-hundredths of the solid, liquid and gaseous matter of the globe is made up of only thirteen elements, the remaining 60 (about) elements comprising only one one-hundredth.

SYMBOLS OF ELEMENTS.

Each element, or strictly speaking, each minute quantity of an element (called an atom) is designated by a letter, or a few letters, called its symbol. For most elements, the symbols are the initial letters of the names, thus for carbon, we write C, for

ELEMENTS.

Names.	Symbol.	Atomic Weight.	Physical condition at ordinary temperature.	Specific Gravity
Aluminum	$Al^{IV.}$	27.	Solid	2.60
Antimony	$Sb^{III, V.}$	120.	"	6.71
Argon	A	20 (?)	Gas	—
Arsenic	$As^{III, V.}$	75.	Solid	5.73
Barium	$Ba^{II.}$	137.	"	3.75
Bismuth	$Bi^{III, V.}$	208.	"	9.80
Boron	$B^{III.}$	11.	"	2.5 (?)
Bromine	$Br^{I, V.}$	80.	Liquid	3.187
Cadmium	$Cd^{II.}$	112.	Solid	8.60
Caesium	$Cs^{I.}$	133.	"	1.88
Calcium	$Ca^{II.}$	40.	"	1.57
Carbon	$C^{IV.}$	12.	"	3.5–.6
Cerium	$Ce^{III, IV.}$	141.	"	6.68
Chlorine	$Cl^{I, V.}$	35.5	Gas	2.450
Chromium	$Cr^{IV, VI.}$	52.	Solid	6.50
Cobalt	$Co^{II, IV.}$	59.	"	8.5–.7
Copper	$Cu^{II.}$	63.3	"	8.95
Fluorine	$F^{I.}$	19.	Gas	1.313
Gold	$Au^{I, III.}$	196.5	Solid	19.32
Hydrogen	$H^{I.}$	1.	Gas	0.069
Iodine	$I^{I, V.}$	127.	Solid	4.948
Iridium	$Ir^{II, IV, VI.}$	193.	Solid	22.42
Iron	$Fe^{II, IV, VI.}$	56.	"	7.86
Lead	$Pb^{II, IV.}$	207.	"	11.37
Magnesium	$Mg^{II, IV, VI.}$	24.	"	1.74
Manganese	$Mn^{II.}$	55.	"	8.03
Mercury	$Hg^{II.}$	200.	Liquid	13.55
Nickel	$Ni^{III, IV.}$	58.	Solid	8.90
Nitrogen	$N^{III, IV.}$	14.	Gas	0.971
Oxygen	$O^{II.}$	16.	"	1.105
Phosphorous	$P^{I, III, V.}$	31.	Solid	{Colorless 1.83 / Red 2.20}
Platinum	$Pt^{II, IV.}$	195.	"	21.50
Potassium	$K^{I.}$	39.	"	0.87
Silicon	$Si^{I.V}$	28.	"	2.39
Silver	$Ag^{I.}$	108.	"	10.53
Sodium	$Na^{I.}$	23.	"	0.978
Strontium	$Sr^{II.}$	87.5	"	2.54
Sulphur	$S^{II, IV, VI.}$	32.	"	2.05
Tin	$Sn^{II, IV.}$	118.	"	7.29
Tungsten	$W^{IV, VI.}$	184.	"	19.12
Uranium	$U^{IV, VI.}$	239.8	"	18.70
Zinc	$Zn^{II,}$	65.	"	7.15

NOTE: The Roman numerals in the second column denote the valence of the element.

hydrogen H, for phosphorus P, etc. Some of the elements have symbols derived from their Latin or Greek names. Thus Au is the symbol for gold, because its Latin name is aurum; similarly Pb signifies lead, since its Latin name is plumbum. In the table, it will be noticed that there are nine elements whose names begin with the letter C. To avoid confusion, carbon has for its symbol, C, and the symbols of the other eight contain an additional distinguishing letter.

As we have said, the symbol stands for one atom. If more than one atom of an element is to be indicated, a subscript or sub-exponent is used. A coefficient is also frequently used to express a number of atoms of the same element. Thus 2Na or Na_2 means two atoms of sodium; and three atoms of iron may be indicated thus, Fe_3 or 3Fe.

Certain groups of atoms remain the same in a series of chemical compounds. To denote a number of these characteristic groups a parentheses and sub-exponent is used. The sub-exponent multiplies all the atoms inside of the parentheses; thus, $(OH)_4$ means four "hydrate" groups, or four atoms of oxygen and four of hydrogen, or O_4H_4.

We may have a molecule of a substance whose atoms are of different elements. Suppose we wish to indicate a molecule of a substance which is made up of one atom of sodium and one atom of chlorine. An atom of sodium is written Na and an atom of chlorine is written Cl. The molecule is indicated by writing the symbols close together as NaCl. A molecule composed of one atom of silver, one of nitrogen, and three of oxygen is written $AgNO_3$.

In case we desire to express 5 molecules of a compound, each molecule containing two atoms of hydrogen, one atom of sulphur and four atoms of oxygen, we write $5H_2SO_4$. This could be written 5 (H_2SO_4). As in arithmetic or algebra, the coefficient 5 means that in the 5 molecules of H_2SO_4 there are $5 \times 2 = 10$ atoms of hydrogen, $5 \times 1 = 5$ atoms of sulphur, and $5 \times 4 = 20$ atoms of oxygen.

Thus it is seen that the sub-exponent applies only to the element which it follows, but a coefficient multiplies all the elements in the compound. In this way Chemistry resembles

algebra. Again, let us examine the formula, $Cu(NO_3)_2$. The sub-exponent 2 is similar to a coefficient and $Cu(NO_3)_2 = CuN_2O_6$; and $(NH_4)_2SO_4$ is the same as $N_2H_8SO_4$.

EXAMPLES FOR PRACTICE.

1. Give names for the following: Cu, Fe, S, Ni, O, Ag, Sn, Al and Zn.

2. Name these elements and state the indicated number of atoms of each; C_7, 3Ni, 4Pt, S_2, Sn_5, O_8 and 2H.

3. Write symbols for 4 atoms of phosphorus, 6 atoms of mercury, 3 atoms of iron and 5 atoms of carbon.

4. How many molecules in each of the following, and how many atoms of each element? $6HgO$, $2CaCl_2$, $3Ca(PO_4)_2$, $2Fe_2(SO_4)_3$, $3Bi_2O_3$.

ATOMIC WEIGHT.

When we say that the specific gravity of lead is 11.37, we mean that lead is 11.37 times as heavy as water. In computing specific gravity we find the weight of a given volume of the substance, and the weight of an equal volume of water. By dividing the weight of the substance by the weight of an equal volume of water, we get the specific gravity. In other words, water is used as the standard or unit when finding specific gravity.

For gases, air is used instead of water. That is, if a gas has a specified gravity of 1.103, it is 1.103 times as heavy as an equal volume of air. In the table on page 7 the specific gravities of solid and liquid elements are referred to water as the standard, and the specific gravities of gaseous elements are referred to air as the unit.

Suppose we could compare an atom of oxygen with an atom of hydrogen; we would find that the atom of oxygen weighed 16 times as much as an atom of hydrogen. Also, if 1000 atoms of iron are compared with 1000 atoms of hydrogen, the iron will be found to be 56 times as heavy as the hydrogen. Since atoms are compared, this relation is called **atomic weight.**

Hydrogen is taken as the unit because its atom weighs less than an atom of any other substance.

The atomic weight of an element is the weight of its atom in terms of the weight of an atom of hydrogen, which is the standard or unit.

From the table we find that the atomic weight of carbon is 12, of nitrogen 14, and of mercury 200.

It is impossible to see an atom, even with the most powerful optical instruments; therefore, it cannot be weighed. However, chemists have determined the atomic weights of the elements by comparing their compounds.

It is assumed that equal volumes of all gases have the same number of molecules if the temperature and pressure are alike. This assumption or law is the foundation of the chemical theory of to-day, and it is accepted by chemists generally.

If a gallon of nitrogen and a gallon of hydrogen are weighed (temperature and pressure constant), the ratio of the weight of the nitrogen to that of the hydrogen is the density of nitrogen. Since both are gases, it is called **vapor density.**

We may define vapor density as follows: *The vapor density of any gas is the weight of a given volume of it in terms of the weight of an equal volume of hydrogen at the same temperature and pressure.*

In making this computation, the gases must be of the same temperature because heat causes gases to expand, and the gas weighed at the higher temperature will contain fewer molecules.

The pressure also must be the same, for the greater the pressure, the greater the number of molecules in a given volume.

At a certain temperature and pressure, a gallon of hydrogen weighs .3264 grams and at the same temperature and pressure a gallon of oxygen weighs 5.2224 grams. The oxygen is consequently $\frac{5.2224}{.3264} = 16$ times heavier than the hydrogen. Then the vapor density of oxygen is 16.

The molecular weight of a gas is twice its vapor density. In other words, the vapor density is one-half the molecular weight. Then, as the vapor density of oxygen is 16, the molecular weight is $2 \times 16 = 32$. If there are two atoms in a molecule of oxygen, and the molecular weight is 32, the atomic weight is $\frac{32}{2} = 16$.

Thus for oxygen, the atomic weight and vapor density are the same, 16 ; but if there are three or four atoms in the molecule of an element, the atomic weight, being equal to the molecular weight divided by the number of atoms, will not equal the vapor density.

Let us consider the gas called carbon dioxide. We write the symbol CO_2 because it is made up of two parts oxygen and one part carbon. The atomic weight of carbon is, from the table, 12; the atomic weight of oxygen is 16, and as there are two atoms of oxygen and one of carbon in the molecule, the molecular weight is

$$12 + (2 \times 16) = 44.$$

The vapor density is one-half the molecular weight, or 22.

By finding the vapor density of gases, chemists have calculated the atomic and molecular weights. This method cannot however be used for some elements, as many substances have never been vaporized or cannot be vaporized under conditions which make weighing possible. For these elements the vapor densities, molecular and atomic weights are uncertain.

Another method is as follows: The atom is the smallest particle which can exist in composition or combination. Hence, the atomic weight is the *least combining weight.* By analyzing a great number of compounds, the smallest weight of an element is determined, and the other compounds contain a multiple of that weight. The least combining weight is the atomic weight.

The vapor density as found by one method and the atomic weight by another are generally the same, that is, if there are two atoms in the molecule. The vapor of mercury has a vapor density of 99½, hence a molecular weight of 199. But the atomic weight is 199, hence there is one atom in a molecule.

MOLECULAR WEIGHT.

The weight of a molecule is found by adding together the weights of all the atoms in the molecule. Molecular weight, like atomic weight, is expressed in terms of the weight of the hydrogen atom.

We know that a molecule of common salt is composed of one atom of sodium, and one atom of chlorine. The sodium atom is 23 times as heavy as the hydrogen atom, or, its atomic weight is

23. The atomic weight of chlorine is 35.5. Therefore the molecular weight of a molecule of salt is $23 + 35.5 = 58.5$. In other words, a molecule of salt is 58.5 times as heavy as an atom of hydrogen.

In the arsenic molecule there are four atoms. The molecular weight is, therefore, four times the atomic weight, or $4 \times 75 = 300$.

A molecule of oxygen has two atoms, hence the molecular weight is $2 \times 16 = 32$.

CHEMICAL AFFINITY.

In order that molecules may be formed from atoms, there must be some force to bind the atoms together. This force is called *chemical affinity* or *chemism*. This force corresponds to the physical force called cohesion.

A compound usually possesses properties which are entirely different from those of the elements of which it is composed. Water, for instance, is made up of two gases, hydrogen and oxygen. These two substances are gases, colorless and ordorless. When combined in the proper proportion, the compound is a liquid at ordinary temperatures.

Sugar ($C_{12}H_{22}O_{11}$), a white, sweet, crystalline substance, is formed by combining carbon, a black non-crystalline substance, with oxygen and hydrogen, two colorless and odorless gases.

Perhaps one of the most striking results of chemical change is found in the substance cupric sulphate, which is expressed by the formula

$$CuSO_4 + 5H_2O.$$

Of the constituent elements, copper is red, sulphur yellow, oxygen is colorless and hydrogen is colorless. Two of these are gases and two are solids at ordinary temperature and pressure. The cupric sulphate thus formed is blue and is a solid. Its color is not like that of any of the constituents, nor is it intermediate between the colors.

Chemical affinity takes away the properties of the elements and causes the compound to have new properties. Chemical affinity may act between atoms of the same kind, or atoms of different kinds. Also, it may be strong or weak, but it acts only at short distances.

It is easy to separate the carbon from the other two elements in sugar, but it is more difficult to resolve water into its elements, hydrogen and oxygen. In other words, it is hard to break up the attraction that some elements have for others, but it can be done by heat, electricity and reagents. A **reagent** is a substance which produces chemical change such as an acid.

COMPOUNDS.

Chemical affinity binds atoms together to form molecules and compounds. Compounds are usually called by names taken from the elements of which they are composed, as hydrogen oxide, H_2O, (*water*), and carbon dioxide, CO_2.

Some compounds are composed of two elements as NaCl, chloride of sodium (*common salt*), and HCl, hydrogen chloride or *hydrochloric acid*. Other compounds contain three elements, as H_2SO_4 sulphate of hydrogen or *sulphuric acid*, and KOH, potassium hydrate.

UNION BY WEIGHT.

Before taking up the study of compounds and equations it will be necessary to understand the proportions in which elements combine. This study is based upon the two fundamental laws of chemistry which are as follows:

1. The law of Conservation of Matter.
2. The law of Definite Weight.

Law of Conservation of Matter. — *The sum of the weights of all the products in an experiment is exactly equal to the sum of the weights of all the factors.*

This law means that matter can neither be destroyed nor created. In other words, matter may be changed or transformed; it may be changed from solid to liquid or to invisible gas, or the volumes may be greatly increased, but the processes do not cause any loss or gain in weight.

Law of Definite Weight. — *Any chemical compound always contains the same elements in the same ratio by weight.*

Ferrous sulphide, FeS, always contains iron and sulphur, and always in the same proportion by weight. Thus, FeS is always made up of 56 parts of iron and 32 parts of sulphur. Potassium chlorate, $KClO_3$, always contains potassium, chlorine

and oxygen. Also, in the compound, there are 39 parts (by weight) of potassium, K; 35 parts of chlorine, Cl; and $3 \times 16 = 48$ parts of oxygen, O.

Water is made from oxygen and hydrogen. Pure water always contains 8 parts oxygen (by weight) and 1 part hydrogen.

Suppose we wish to make oxygen from the compound, potassium chlorate, $KClO_3$. How much oxygen can we expect from 2 ounces?

First, we must know what proportion of the $KClO_3$ is oxygen. We know that there are 39 parts K, 35 parts Cl, and 48 parts O. Then of 122 parts, 48 are oxygen, and $\frac{48}{122} \times 2 = .787$ ounces (nearly).

VALENCE.

Atoms of the various elements differ in the number of atoms of other elements which they can hold in combination to form chemical compounds. Let us suppose that atoms have "hands" or "hooks" with which they can grasp other atoms. Some atoms have one hand, some two, some three, and so on. It is evident that an atom with two hands can hold two atoms having one hand, or it can hold one atom which has two hands, etc. Or we may consider that an atom has a certain number of "affinity points." The number of these affinity points determines the number of atoms which it can hold in chemical combination. This is what is known as the *valence* or quantivalence of an atom. Valence has no apparent relation to the strength of the affinity of atoms.

The term valence is used in regard to an element only. The combining power of hydrogen is a convenient measure of valence as its valence is always 1; in other words it seems to have but one "affinity point," or "hand." With elements which combine directly with hydrogen the valence is the number of hydrogen atoms which one atom will hold. Atoms which do not combine with H will usually replace H in its compounds and the number of atoms of H which such an atom will replace is its valence. Thus in NaCl the Na replaces one atom of H in HCl. Hence the valence of Na is 1. In H_2O one atom of O combines with two atoms of H, therefore the valence of O is 2. We may say that the

hydrogen atom has one hook; two atoms must therefore have two hooks, and as oxygen is combined with two atoms of hydrogen, the oxygen element must have two hooks. Hence the valence is two. Fig. 1 shows some of the ways of representing the valences of elements.

Ammonia is a gas made up of three atoms of hydrogen and one atom of nitrogen; its symbol is then NH_3. What is the valence of N? The valence of hydrogen is one, and as one atom of nitrogen combines with three atoms of hydrogen, the valence of nitrogen must be three.

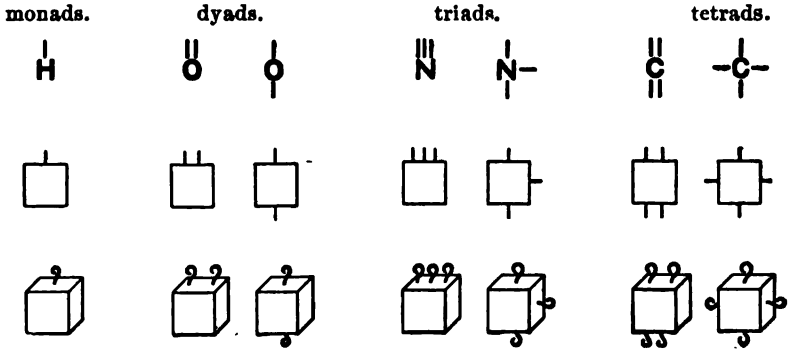


Fig. 1.

What is the valence of sodium, magnesium, bismuth and carbon from these symbols?

$$NaCl,\ MgCl_2,\ BiCl_3,\ CCl_4.$$

In NaCl, it is seen that one atom of sodium, Na, combines with one atom of Cl, hence its combining power is one. Again, we have the two compounds HCl and NaCl. From these symbols it is seen that one atom of Na replaces one atom of H, therefore the replacing value of Na is one.

In magnesium chloride, $MgCl_2$, one atom of magnesium combines with two atoms of chlorine. The valence of Mg is therefore two.

Chloride of bismuth, $BiCl_3$, is made up of one atom of bismuth and three atoms of chlorine. Then as one atom of Bi combines with three atoms of Cl the combining value of Bi is three.

Similarly four atoms of chlorine are necessary when combining with one atom of carbon, and the valence of C is four.

If these compounds were made by the action of HCl, the equations would be

$$Na + HCl = NaCl + H.$$
$$Mg + 2HCl = MgCl_2 + 2H.$$
$$Bi + 3HCl = BiCl_3 + 3H.$$
$$C + 4HCl = CCl_4 + 4H.$$

When an element combines with hydrogen, atom for atom, or replaces hydrogen, atom for atom, its valence is one and it is called *univalent.* The *bivalent* elements are those which require two atoms of hydrogen to replace one atom of the element, and the *trivalent* elements are those whose atoms select three atoms having a valence of one with which to unite. These elements are called monads, dyads and triads, etc.

Some elements have more than one valence. Phosphorus sometimes combines with three atoms of chlorine (PCl_3) and sometimes with five atoms (PCl_5). In the first case P is a triad, and in the second case a pentad.

The valence of an element is often indicated by marks at the right, as Na', Cu'', Bi''', C^{IV}.

EQUATIONS.

A chemical equation (sometimes called a reaction) is a short algebraic expression of a chemical change. If we heat together iron filings and sulphur, the result is iron sulphide, or we can say that

$$\text{iron} + \text{sulphur} = \text{iron sulphide.}$$

We know that a definite quantity of iron united with a definite quantity of sulphur, and the result was a definite quantity of iron sulphide. We may say that one atom of sulphur united with one atom of iron and formed a molecule of iron sulphide. Let us use the symbols of these elements and we can write,

$$Fe + S = FeS.$$

In fact, millions of atoms of iron united with an equal number of atoms of sulphur; but for simplicity and brevity, we write the equation for one atom of each.

The atomic weight of iron is 56, and that of sulphur is 32. Then 56 parts, by weight, of iron united with 32 parts by weight, of sulphur, to form 88 parts of iron sulphide.

	Factors.		Product.
	$Fe + S$	$=$	FeS
	$56 + 32$	$=$	88

An equation represents the substances that are put together, and the substances obtained. Also, it shows the proportions of those used and of those obtained. Substances put together are called Factors, and those obtained Products. The factors are usually placed on the left-hand side of the equality sign, and the products on the right-hand side.

From the law of conservation of matter, we learned that matter cannot be created or destroyed. Therefore there must be as many atoms in the products as there were in the factors. Also there must be the same number of each kind of atoms on both sides of the equation.

Take the action of hydrochloric acid, HCl, on metallic zinc, Zn; the zinc disappears and bubbles of gas are given off.

$$Zn + HCl = ?$$

We know that hydrogen is given off. The valence of Zn is two, or, one atom of Zn will replace two atoms of H; but there is only one atom of H in one molecule of HCl; therefore we must have two molecules of HCl to give two atoms of H to be replaced. The equation (or reaction) then will be:

	Factors.		Product.
	$Zn + 2HCl$	$=$	$ZnCl_2 + 2H$
by atoms	$1 + [2 \times (1 + 1)]$	$=$	$(1 + 2) + 2$
or	$1 + 4$	$=$	$3 + 2$

The zinc replaces the hydrogen and combines with the chlorine, forming zinc chloride, $ZnCl_2$, and the hydrogen gas is set free. It is evident that there are five atoms on each side of the equation, also that on each side one of these is an atom of Zn, two are atoms of H and two are atoms of Cl.

Suppose sulphuric acid, H_2SO_4, is added to caustic soda, NaOH. Sulphate of soda, Na_2SO_4, and water, H_2O, will be formed.

$$NaOH + H_2SO_4 = Na_2SO_4 + H_2O — ?$$

We see that there are two atoms of Na in the products and only one in the factors, also three atoms of H on the left and only two on the right; therefore we must have two molecules of NaOH to furnish two atoms of Na, and the expression will then become

$$2NaOH + H_2SO_4 = Na_2SO_4 + 2H_2O$$

By atoms

$$2\times(1+1+1)+(2+1+4)=(2+1+4)+[2\times(2+1)]$$

or $$6+7=7+6$$

The equation will now balance, for there are thirteen atoms on each side and also the same number of atoms of Na, O, H and S in the factors as in the products.

We may write many chemical equations which do not express chemical reactions. In order to write a true chemical reaction (equation) it must be known that a chemical action takes place and also what substances are formed.

Use of Chemical Equations. From the study of atomic and molecular weights we can find the weights of all factors used and all the products made in terms of the weight of an atom of hydrogen. Let us again consider the equation of the action of HCl on Zn.

$$Zn + 2HCl = ZnCl_2 + 2H$$

By weights this becomes $$65 + 73 = 136 + 2$$

For the atomic weight of Zn is 65, the molecular weight of $HCl = 1 + 35.5$, and of $2HCl = 2 \times 36.5 = 73$. The molecular weight of $ZnCl_2 = 65 + (2 \times 35.5) = 136$, and the weight of $2H = 2$.

Example.—How much hydrochloric acid will be required to dissolve 10 pounds of zinc? We see by the chemical equation that 65 parts by weight of zinc are dissolved in 73 parts by weight of HCl. The problem is then one of simple proportion.

Zn : 2HCl : : zinc : hydrochloric acid

65 : 73 : : 10 lbs. : x lbs.

$65x = 730$ $x = 11.23 +$ lbs. zinc.

If more zinc is taken, the excess over 10 pounds will be left unacted upon, or if more than 11.23+ pounds of HCl is added to 10 pounds of zinc, the excess HCl will not be used up.

Another example: How much zinc chloride, $ZnCl_2$, will be produced from the 10 pounds of zinc?

Zn : $ZnCl_2$: : zinc : zinc chloride

65 : 136 : : 10 : x

$65x = 1360$ $x = 21$ lbs. (nearly) of zinc chloride.

Thus we see that if we have the chemical equations and atomic weights we can calculate all the products and factors if we know the weight of one factor or product. This is very important in all chemical work.

EXAMPLES FOR PRACTICE.

(1) Complete the following:

(*a*) $S + ? = SO_2$ (*b*) $Fe + ?HCl = FeCl_2 + ?H$

(*c*) $CaCO_3$ (heated) $= CaO + ?$

(*d*) $Na_2CO_3 + ?HCl = ?NaCl + H_2O + CO_2$

(2) $C + 2O = CO_2$. How much CO_2 (carbon dioxide) will be made from 10 pounds of carbon? Ans. $26\frac{2}{3}$ pounds.

(3) $S + 2O = SO_2$. How much sulphur will be required to make 20 pounds of SO_2? Ans. 10 pounds.

(4) $Na_2CO_3 + H_2SO_4 = Na_2SO_4 + H_2O + CO_2$. How much sulphuric acid will be required to neutralize 12 pounds of sodium carbonate, Na_2CO_3? Ans. 11.1 pounds.

CHEMICAL ACTIONS.

Chemical action does not always take place when substances are mixed; but from countless experiments several general facts governing chemical action can be mentioned. Many of the elements are active chemically. Thus oxygen combines directly (forming oxides) with all elements except florine and argon; sulphur unites with many of the metals, forming sulphides; chlorine, bromine, and iodine form chlorides, bromides and iodides respectively. The oxygen in many compounds is easily separated, making them chemically active. They are called oxidizing agents, and as examples bichromate of potash, nitric acid, potassium chlorate and bleaching powder may be mentioned. Compounds called acids are very active chemically.

An Acid is a compound containing hydrogen which can be easily exchanged for a metal or other basic substance. Acids have

a sour taste and cause effervescence when added to a carbonate, as, for instance, baking soda.

Basic Elements are the common metals and elements which act like them. Sodium, potassium and calcium are in reality metals and are much more "basic" than the familiar metals.

An Alkali is formed when a very basic element displaces one atom of hydrogen in H_2O forming a hydrate thus: $Na + H_2O = NaOH + H$. NaOH is called a sodium hydrate.

The hydrogen of an acid is easily exchanged for a metal when treated with an alkali. When the correct proportion of an acid is added to an alkali or other basic compound the characteristic properties of both the acid and base are lost. The acid and alkali are said to neutralize each other.

Salts. The substance formed by neutralizing an acid is called a salt. Water is also formed when a hydrate or an oxide is used to neutralize an acid.

(1) $HCl + KOH = KCl + H_2O$

(2) $2HNO_3 + Ca(OH)_2 = Ca(NO_3)_2 + 2H_2O$

(3) $H_2SO_4 + ZnO = ZnSO_4 + H_2O$.

When a metal is used, hydrogen is set free. Thus:

$$Fe + H_2SO_4 = FeSO_4 + H_2$$

The substances KCl, $Ca(NO_3)_2$, $ZnSO_4$ and $FeSO_4$ are salts, and are neutral substances with little chemical action.

When a volatile substance can be given off, chemical action will usually take place. Strong acids will displace weaker acids in salts; as, for example, $HCl + FeS = FeCl_2 + H_2S$. Hydrogen sulphide, H_2S, is a gas and is expelled.

$$2HNO_3 + Na_2CO_3 = 2NaNO_3 + H_2O + CO_2.$$

Carbon dioxide, CO_2, is given off when a strong acid is added to a carbonate. Heating frequently assists the action. Nitric acid, HNO_3, is made by heating nitrate of soda with sulphuric acid; and hydrochloric acid, HCl, by heating common salt with sulphuric acid.

The reactions are:

(1) $H_2SO_4 + 2NaNO_3 = NaHSO_4 + HNO_3$

(2) $H_2SO_4 + 2NaCl = Na_2SO_4 + 2HCl$.

Solutions of all neutral salts can be mixed without apparent chemical action, unless an insoluble compound is formed. For

example, a solution of common salt can be mixed with a solution of nitrate of soda without change. There are, however, many insoluble salts, of which lead sulphate is one. If a solution of lead nitrate be added to a solution of sodium sulphate, the mixture becomes white like milk, and after a short time a white powder, lead sulphate, $PbSO_4$, settles to the bottom. $Pb(NO_3)_2 + Na_2SO_4 = 2NaNO_3 + PbSO_4$. This is called a *precipitate*, because it is thrown down. The precipitate will continue to form until one or the other of the salts is exhausted.

Solubility. Many substances will dissolve in water, such as

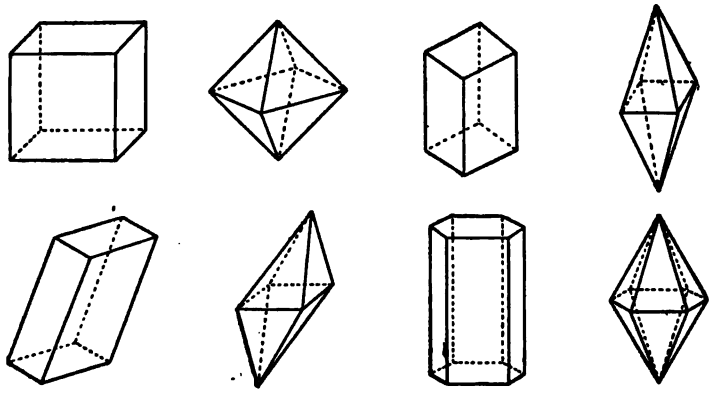


Fig. 2.

salts, acids, alkalis, sugar and gases. If a salt (or sugar) is placed in water, it disappears. If more and more salt is added, a point will at length be reached when no more salt will be dissolved. The solution is then said to be saturated. If, however, the saturated solution is heated, more salt (or sugar) can be dissolved. That is, in most cases heating water increases its capacity for retaining solids in solution. The reverse is true of gases, for more gas can be dissolved in cold water than in hot water.

If a hot saturated solution of a solid is cooled to ordinary temperature, some of the solid will be thrown out of the solution, or precipitated. The precipitate is often formed in very beautiful crystals, especially if the solution is cooled slowly. A few of the shapes are shown in Fig. 2.

OXYGEN.

Occurrence. — Oxygen is one of the most important elements. It is important because of its abundance, its activity, and the great number of compounds into which it enters. Oxygen makes up by weight fully one-half of the globe, including air, ocean and earth. The air is about one-fifth oxygen by weight; water is eight-ninths oxygen by weight, and the important minerals such as quartz, sand, &c., are about one-half oxygen.

The oxygen in water and in minerals is chemically combined, but when in air, it is simply mixed with the other gases.

Oxygen is essential to all animal matter. It sustains the vitality of man, of beasts and even of fish. Oxygen supports combustion, whether a single splinter is burning, or there is a great conflagration.

Discovery. — The first discovery of oxygen is generally attributed to Dr. Joseph Priestly, an English clergyman and scientist. Priestly performed his great experiment August 1, 1774, and this day has been called the birthday of modern chemistry.

So great was the interest in chemistry at this time, that two others discovered this important element at about the same time that Priestly did. These two were Scheele, an apothecary in Sweden, and Lavoisier, the French chemist. Scheele called it "fire air," but Lavoisier named it oxygen which means "acid former."

Lavoisier in giving the true explanation of combustion overthrew the Phlogiston theory and started modern chemistry.

Physical Properties. — Oxygen is a gas at ordinary temperatures and pressures. It is colorless, tasteless, odorless and a little heavier than air. It is soluble in water; it is to this property that fish owe their existence. About one volume of oxygen can be dissolved in 25 volumes of water.

Oxygen was, until recently, considered a permanent gas, that is, it could not be liquified. Experiments, conducted with apparatus capable of subjecting it to intense cold and great pressure, show that the gas can be liquified.

Chemical Properties. — The most striking of the chemical properties is the tendency to combine with other elementary

substances. This is the reason for oxidation, rust and the decay of so many substances. Combustion is another example, but in this instance the oxygen does not unite except when the substances are heated. Thus, a building is surrounded and saturated, as it were, with oxygen, but it is harmless until heat produces combustion; then the oxygen combines with the other elements.

Oxygen is called a supporter of combustion. In fact, diamonds, iron and other substances, not ordinarily considered combustible, will burn brilliantly in pure oxygen gas.

At usual temperatures, oxygen combines slowly. If a piece of iron is made bright and then dipped in water, it becomes rusted in a few days; or if a piece of lead is filed until it is bright, it becomes covered with a dull colored coating of oxide of lead.

If air were undiluted oxygen, all animal life would be rapid. If a fire was started, it could be extinguished with difficulty.

Compounds. — As has been stated, oxygen combines with almost all of the elements. These compounds are called oxides.

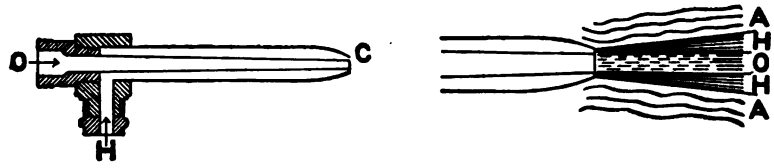


Fig. 3.

The most important of these is water. The compounds of oxygen which are the most important to the engineer, are water and the products of combustion. Oxygen is an important constituent of air, but air is a mixture and not a chemical compound. These substances, water, air and the products of combustion will be discussed later.

Uses. — The principal use of oxygen in nature is to sustain life. It also supports combustion. It is used in the oxy-hydrogen blow-pipe, and in the production of the calcium light.

The oxy-hydrogen blow-pipe consists of two concentric tubes, the inner one conveying oxygen and the outer hydrogen, as shown in Fig. 3. The gases come together at the end and are burned. The flame is almost colorless and has but little luminous power.

Its heat is, however, intense; the temperature being about 2000° F. This intense heat is made use of in melting and refining ores and alloys.

The calcium or lime light is made by directing the flame from the oxy-hydrogen blow-pipe upon a block or cylinder of lime. The intense heat produced by the burning of the gases, causes the lime to become white hot, and to give out a brilliant, dazzling light. Illuminating gas can be used in place of hydrogen. The calcium light is used for stereopticons, and for stage effects in theatres. It has been used in carrying on important engineering construction work during the night. At the present time, the electric light is taking the place of the lime light to a great extent.

Preparation. — Oxygen may be prepared in many ways. Priestly prepared it by heating red oxide of mercury. The process is represented by the equation,

$$2HgO = O_2 + 2Hg.$$
$$2\,(200 + 16) = 32 + (2 \times 200).$$
$$432 = 432.$$

The most usual method of preparing oxygen is by heating a substance called chlorate of potassium ($KClO_3$). The following formula explains the chemical change,

$$2\,KClO_3\ (\textit{heated}) = 2\,KCl + 3O_2$$

The heat sets free the oxygen and changes the chlorate of potassium to potassium chloride.

This substance, $KClO_3$, breaks up only at a comparatively high temperature and with explosive violence; but by mixing with it a little manganese dioxide (called black oxide of manganese) much less heat is required, and the oxygen evolves slowly and continuously. The manganese dioxide does not appear to take any chemical part in the process, but remains unchanged.

HYDROGEN.

Occurrence. — Hydrogen is rarely found on our globe uncombined or in a free condition. The reason for this is its great affinity for oxygen which is so abundant. In combination, hydrogen is very abundant and widely distributed. Hydrogen is in all water, wherever it may be. Besides water in the form of oceans, lakes, rivers, etc., it is one of the principal elements in animal and

vegetable life. Hydrogen is a constituent of natural gas, meteorites, and most acids and bases.

Discovery. — Hydrogen was isolated in 1766 by an English chemist, Cavendish, who called the gas "inflammable air;" but Lavoisier named it *hydrogen* which means "*water former.*"

Cavendish was a very eccentric individual, having scientific pursuits the object of his life. His silent accurate work did much toward the progress of the science of Chemistry.

Physical Properties. Hydrogen is the lightest of gases, being only $\frac{1}{16}$ as heavy as oxygen. When pure it is colorless, odorless and tasteless. It is but slightly soluble in water. On account of its lightness it was formerly used for inflating balloons, but as hydrogen is expensive, illuminating gas is now used, although it is much heavier than hydrogen.

Hydrogen has been liquefied at—238° C and under a pressure of 300 pounds per sq. in. Also it has been solidified by Dewar.

Chemical Properties. — The most interesting and most striking property of hydrogen is its power to unite with oxygen. When oxygen and hydrogen unite, heat, light and flame appear, and a new chemical compound is produced. These are the phenomena of combustion.

Hydrogen will not unite with most metals. For a few elements, it has great attraction. Hydrogen combines with boiling sulphur, and has a strong affinity for chlorine, forming hydrochloric acid, HCl.

Under ordinary conditions, hydrogen will not combine with carbon, but there are hundreds of compounds of hydrogen and carbon, called hydrocarbons, CH_4, C_2H_6, etc.

Hydrogen burns in oxygen or in the air with a blue, almost colorless flame, of great heat. One pound of hydrogen will give out more heat in burning, than will a pound of any other substance.

As to its being a substitute for air, hydrogen in this respect differs radically from oxygen. Hydrogen will not support animal life, neither will it support combustion. An animal placed in a room filled with hydrogen expires almost immediately. If a candle, or a lighted match is placed in a jar of hydrogen, it goes out. The hydrogen seems to deprive the animal or the candle of their necessary oxygen.

Compounds. — Compounds containing hydrogen are exceedingly numerous; water, acids and hydrocarbons being among the most common.

Uses. — As an elementary gas, hydrogen has few uses. Its great lightness made it a desirable substance for balloons, and its great heating power made it invaluable for the oxy-hydrogen blow-pipe. However, on account of the high cost of hydrogen, illuminating gas is now used extensively in the above cases. It is, however, used by the chemist as the unit for density and atomic weight, and as the standard for valence. The great value of hydrogen is in its compounds rather than in an uncombined state.

Preparation. — The chemist can obtain hydrogen in many ways. As water is composed of oxygen and hydrogen, it is only necessary to decompose water into its constituent elements. This is done by means of an electric current.

The most common way to produce hydrogen is by the action of sulphuric acid on zinc. However, hydrochloric acid and other metals beside zinc can be used. The acid should be diluted somewhat, so that it will readily act on the zinc. The chemical change is represented by the following reaction:

$$Zn + H_2SO_4 = ZnSO_4 + H_2$$
$$65 + 98 = 161 + 2$$

In this experiment, zinc has changed places with the hydrogen and the hydrogen is left without anything with which to combine.

Hydrogen thus produced is seldom pure, as the various substances used are likely to contain substances which give some impurity to the gas thus formed.

WATER.

Now that we know something of the elements, oxygen and hydrogen, we can study the most important compound of these two elements.

The chemical history, properties and uses of water are both interesting and important, and if treated with any degree of thoroughness would furnish material for a volume.

Water is very abundant; it is necessary to both animal and plant life, and is extremely useful to man.

As to its abundance, one has but to look out upon the ocean from a high cliff to become convinced of the enormous quantity.

The oceans cover over three-fourths of the surface of the earth, and their depths may be measured in miles. Besides the ocean, there are numerous lakes, rivers, canals, &c.

Water is essential both to animals and plants. If water were banished from the earth, all animals would die almost instantly, and the vegetables would soon cease to grow. The blood which courses through our bodies is about seven-eighths water. The human body itself is more than half water. Vegetables, which form such a large part of the food of animals, are made up largely of water. Cucumbers contain about 97 per cent. water, and it is said that some forms of jelly-fish have been found to contain 99.9 per cent. of water.

Besides being necessary to the existence of man, water aids him in many ways. The oceans, rivers and lakes are the great highways upon which man carries on commerce. Many factories are run by water-power. But to the engineer, water, as water and steam, is of great importance. In most cases, it is the steam engine that furnishes power directly, or develops it to be transmitted by electricity or by compressed air.

Properties. — Water exists in three states, solid, liquid and gaseous. At ordinary temperature (60° F.) it is a liquid. As it is cooled it contracts slightly, until it reaches 39.2° F. expanding slightly thence to the freezing point 32° F. This property is of great value; when water freezes it expands, and as it then occupies a greater volume it becomes relatively lighter. On this account, ice rises to the surface of a lake and stays there forming a covering which prevents the water from becoming uninhabitable for fish. The same property prevents a lake from becoming a solid mass of ice which could not be melted by the summer sun. The expansion at the moment of solidification also causes the water in the crevices of rocks and in the soil to break up the rocks and prevent the surface of the soil from becoming hard.

Let us consider what effect water has on the climate. The heat of the sun in the tropics changes water into vapor; this vapor is carried by the winds to the colder portions of the earth where it is condensed and falls as rain or snow. In order to turn water into vapor, heat must be applied and stored up in the vapor.

When the vapor is condensed into water, heat is given out by the vapor. This process makes the tropics cooler, because heat is taken from the atmosphere and absorbed by the vapor, and makes the cold portions of the globe warmer because heat is evolved.

Thus the circulation of vapor is like a steam heating plant. The boilers are at the tropics, and the condensers, or radiators, are all over the globe. The sun's rays make the steam. This apparatus has the same principle as a boiler, but it works without tubes, shell or radiators.

There is another way that water tends to regulate the climate. In the hot days of summer, the water of a lake or the ocean becomes warmer. However, it takes more heat to raise the temperature of water one degree than it does to raise the land one degree. Thus, the water will absorb a large amount of heat without having its temperature raised to the extent that might be expected. In hot weather, heat is absorbed by the water, but its temperature is not very high, and as its temperature is low, it has a tendency to cool the surrounding land. Now in cold weather, the store of heat in the water is given out as the water cools. We may say that the ocean or a large lake, is a great reservoir, storing up the heat of summer, and giving it out in winter. This is the reason why the temperature near the ocean is not subject to as great variations as is that of the country far inland.

We know that water is formed of oxygen and hydrogen. This is true, but water as it is found on the earth is never absolutely pure. The fact that so many substances readily dissolve in water accounts for the numerous impurities. As rain falls from the clouds, it absorbs gases and solids. When it flows as a river, it dissolves small quantities of the substances with which it comes in contact.

There are two kinds of impurities, organic and inorganic. Organic matter usually tinges water yellow. Salts in spring waters are taken from the rocks and soil through which the water flowed.

Hard Water.— If water contains lime salts or magnesium salts in solution, it is called hard water. The reason why it is called hard is because of its action on soap. Soft water forms a lather and cleanses the skin, but hard water does not form a

lather; the soap combines with the salts to form insoluble lime or magnesium compounds that appear as a scum on the surface. If water contains calcium bi-carbonate, $CaH_2(CO_3)_2$, the CO_2, may be expelled by boiling. The calcium carbonate, $CaCO_3$ is precipitated and appears as a crust or scale. If the water contains calcium sulphate, $CaSO_4$ it may be softened by means of sodium carbonate, $NaCO_3$.

Distillation. Water may be purified by distillation. This process consists in heating water to steam and then condensing the steam. Since most of the impurities are less volatile than water, the salts in the solution are left behind making the condensed steam, pure water. The apparatus used in distilling water is called a still and consists of a vessel for heating and vaporizing the water (called a retort) and a curved tube (called the coil or worm) for cooling the steam. The worm is surrounded by cold water. In Fig. 4 steam enters at A and when condensed flows out at B. The cooling water enters at C and flows out at D.

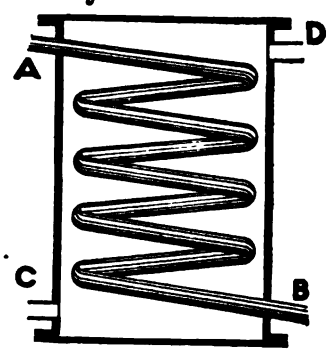


Fig. 4.

Distilled water has a flat taste and is used but little for drinking.

NITROGEN.

Occurrence.—Nitrogen is a gas which is the chemical opposite of oxygen. Nitrogen exists in the air, and in a few compounds. It occurs free in the atmosphere, of which it is about 77 per cent. of the volume. The most common compounds containing nitrogen are the nitrates; potassium nitrate (KNO_3), and sodium nitrate ($NaNO_3$). Ammonium compounds, such as ammonium chloride (NH_4Cl), are also common.

Organic matter, both vegetable and animal, contains compounds of nitrogen.

Discovery.—Nitrogen was discovered or rather recognized as a constituent of air about the time when Cavendish, Priestly, Scheele, Lavoisier and other noted chemists were making such wonderful discoveries. At this time Rutherford showed that after

animals have breathed in a certain volume of air, an inert gas is left behind.

Lavoisier named the gas azote, but Chaptal named it *nitrogen*, because of its existence in nitre, KNO_3.

Physical Properties.— Nitrogen, if pure, is a colorless, tasteless and odorless gas. It is a little lighter than air. By means of intense cold and great pressure, this gas, like others, has been liquified.

Chemical Properties.— The most striking property of nitrogen is extreme inactivity. It is very inert. It does not burn nor does it support combustion. It is not poisonous, but it gives no aid in supporting life. At high temperatures, nitrogen unites with some elements, but at ordinary temperatures it does not enter into chemical union with other substances.

Although inertness is the marked characteristic of nitrogen, yet this element is a constituent of many compounds which are active to a high degree. Among these are such explosives as gunpowder, nitro-glycerine and dynamite.

Compounds.— Many important compounds contain nitrogen. In nature, nitrogen is necessary to both animal and plant life. It is an important element of muscular fibre and of brain material. It is a constituent of ammonia gas, NH_3, and of a large number of compounds derived from it, which are so essential to plants.

Ammonia.— NH_3 is the principal compound of nitrogen and hydrogen. It is a colorless gas, having a very pungent odor and acrid taste. It is very soluble in water. Ammonia can be liquified and solidified by cold and pressure. Upon evaporating, ammonia absorbs heat, thus producing cold sufficient to freeze water. This property is made use of in refrigerating machines.

Ammonia and hydrochloric acid form ammonic chloride, NH_4Cl, a salt called sal ammoniac,

$$NH_3 + HCl = NH_4Cl.$$

With hydrogen and oxygen, nitrogen forms nitric acid, HNO_3, one of the three most important acids.

Uses.— The principal use of nitrogen is to dilute the active oxygen in the air and make the mixture suitable for breathing. Also on account of the dilution of the oxygen, the nitrogen prevents oxygen from having too rapid action in combustion. The

uses of this gas in animal and plant life have been mentioned. Nitrogen unites with oxygen and forms several oxides, one of which, N_2O, is called laughing gas.

Preparation.—Nitrogen may be prepared from air by separating the other constituents from it. As oxygen is the other principal element, it may be burned out by means of phosphorus. As the air is confined in a jar, the burning phosphorus withdraws the oxygen leaving nitrogen. The union of oxygen and phosphorus may be expressed by the equation,

$$2P + 5O = P_2O_5.$$

The P_2O_5 is dissolved in water leaving nitrogen.

Nitrogen may also be separated from oxygen by passing dry air over red-hot copper confined in a tube.

$$Cu + O = CuO.$$

THE ATMOSPHERE.

The atmosphere, or air, which surrounds our globe is a vast ocean of gases. Human beings and other land animals dwell at the bottom of this ocean. The height to which the air extends is not known exactly. Formerly, it was supposed to extend about 50 miles from the surface of the earth; but at the present time some people think it extends to other planets.

Experiment shows that the density of air diminishes rapidly as one ascends. It has been calculated that at the height of about 40 miles the air is as rare as in the so-called vacuum of a good air pump. This calculation seems to show that if the atmosphere extends to the other planets, it must be exceedingly rare.

The ancients thought there were four elements, *earth*, *air*, *fire* and *water*. They called any gas air in the same way that any thin liquid was water. Until Priestly discovered oxygen, air was considered an element. Lavoisier was the first to make an analysis of the atmosphere.

Constituents.—There are five principal constituents of air. These are nitrogen, oxygen, argon, water (as a vapor) and carbon dioxide. Besides these, there are a great many other less important gases. Nitrogen, oxygen, and argon are called the permanent constituents, because their proportion is very nearly constant. The amount of water is very variable. Winds from deserts con-

tain but little moisture; during the rainy season the atmosphere is almost constantly at the dew-point.

Suppose the air contains a certain amount of moisture. Now as the temperature of the air is lowered, a temperature will at length be reached at which the air will be just saturated with moisture. Further reduction of temperature will cause a part of this moisture to be precipitated. The temperature at which the air is just saturated is the dew point for the air under consideration. The dew point varies with the amount of moisture in the air.

Carbon dioxide, CO_2, forms 3 or 4 parts in 10,000 of the atmosphere. In the air above cities, in theatres, and in crowded rooms, the percentage is much larger. Although the percentage of CO_2 is small, yet the total quantity in the air is great.

Of the permanent constituents, nitrogen (the inert gas) forms about four-fifths of the whole; oxygen (the active element) forms about one-fifth, and argon nearly one per cent.

Argon is a comparatively new element, being discovered in 1894. It was found that when nitrogen was obtained from the atmosphere it was $\frac{1}{2}$ per cent. heavier than when made from chemical compounds. This fact lead to its discovery. Argon is of little importance. Its resemblance to nitrogen accounts for the late discovery. It is the most inert of all known substances, and combines chemically with no elements. It is more soluble in water than nitrogen, and has been liquified at $-121°$ under a pressure of about 750 pounds per square inch. It freezes at $-191°$.

Besides the large number of gases found in the atmosphere, there are minute quantities of solid materials of many kinds. For instance, common salt is blown up into the atmosphere from the waves of the ocean and carried far inland.

The atmospheric ocean is like the liquid ocean in one respect. While rivers flow to the ocean, they carry along pulverized rock, vegetable matter, impure products from manufacturing establishments and washings from the soil. All these impurities find their way to the ocean. In the case of air, all living animals pour out with every breath from the lungs, waste materials from their bodies. Wherever fuel is burned or wherever a manufacturing plant allows the escape of gases or vapors or pulverized solids,

these are mingled with the atmosphere. Thus the air is a great reservoir, in which are found almost all gaseous substances.

The various constituents of air exert various influences upon it. The oxygen is the active constituent; it is the portion necessary to the existence of animals and combustion.

The chief duty of the nitrogen is to dilute the oxygen and weaken its excessive activities. Let us consider what would happen if the air were made up entirely of oxygen. It has already been said that iron and other metals burn in pure oxygen. Then if the air were pure oxygen, the heat in stoves would cause the iron to burn and the result would be that there would be no restraining the conflagation. The influence of argon is practically the same as that of nitrogen which it so strongly resembles.

The moisture in the air is of great value to animal and plant life. We know that water has a great capacity for retaining heat. When the sun's rays penetrate the atmosphere, some of the heat is absorbed by the earth and then imparted to the air above it. The moisture in the air hinders the escape of this heat. The heat thus imprisoned, as it were, greatly aids the growth of animals and plants. The earth imparts heat only to the layer of air immediately above it, as is shown by ascending a mountain; the vegetation may be luxuriant at the base, but as the mountain is ascended, the richness of vegetation diminishes and a height is soon reached where perpetual cold and snow prevail; no animals exist and only the lowest forms of vegetation can be found.

The glories of the sunrise and sunset are due to moisture in the air. The light shining through the drops of water that float about in the form of clouds, produces the beautiful effects.

Carbon dioxide, the fifth important constituent of air, is formed as has already been stated, when combustion takes place either in a fire or in animals. When an animal breathes, minute particles of animal tissue are burned, and one of the products of this combustion is carbon dioxide. For this reason, the animal body has been likened to a furnace.

On account of the large number of animals on the globe, and the immense quantity of coal that is burned, one might think that the carbon dioxide by continually increasing would soon form a large proportion of the atmosphere. Nature has wonderfully

provided for this. The carbon dioxide, which is the waste matter of animals, is one of the foods for plants. Thus the trees of the forest are continually taking in the carbon dioxide and giving out pure oxygen, which is at the same time the refuse of plants, and the life giving oxygen which animals demand.

CHEMISTRY OF AIR.

On account of the abundance and importance of air, it has been studied with great care. It has been carefully analyzed. Experiment shows that air seems to be a chemical compound by reason of one fact — the two principal constituents, oxygen and nitrogen, have been found to exist in almost constant proportions. Every other consideration, however, seems to show that air is a mechanical mixture.

If air were a chemical compound, the proportions of the constituents would not vary, but the amount of oxygen is found to vary from 20.908 to 20.999 per cent.

Among other reasons for thinking air a mixture, is the following: Suppose air were composed of exactly 20 per cent. oxygen and 80 per cent. nitrogen, then the symbol would be N_4O. If four volumes of nitrogen are mixed with one volume of oxygen, the mixture behaves like atmospheric air. When the gases are brought together, no heat is either liberated or absorbed; also there is no condensation. These phenomena are observable in the case of chemical union. An investigation of the vapor density, also shows the air to be a mixture, and not a chemical compound.

CARBON.

Occurrence. — Carbon exists in nature in many forms. It is seldom found pure or uncombined, although many substances are made up largely of carbon. Carbon exists in three distinct forms; **amorphous carbon, graphite and diamond.** Amorphous means not crystalline. Graphite and diamond are the crystalline forms. Although these three forms bear no resemblance to one another, and their properties differ considerably, yet they are all varieties of the same element.

Discovery. — Carbon, as charcoal, was thought by the phlogistonists to be very pure phlogiston, because it burned leaving

but little residue. Graphite was known to the alchemists; pencils were made of it in the sixteenth century. In 1772, Lavoisier burned a diamond, thus proving that it was not quartz. In 1796, equal weights of diamond, graphite and charcoal were burned, giving equal weights of carbon dioxide, CO_2. This proved that all these three substances were forms of carbon.

AMORPHOUS CARBON.

Amorphous carbon exists as charcoal, bone-coal, lamp-black, coke, gas carbon and mineral coal. Of these, mineral coal is found in the earth, the other forms being artificial products.

Charcoal is probably the most familiar form of carbon. Charcoal is not pure carbon, as it contains minerals and other impurities. It is made by heating wood without burning it, or only partially burning it. By heating wood for a time out of contact with air, the compounds which form the fiber are broken up and the gases driven off or burned. This process is called distillation, and as the compounds are destroyed, it is sometimes called destructive distillation.

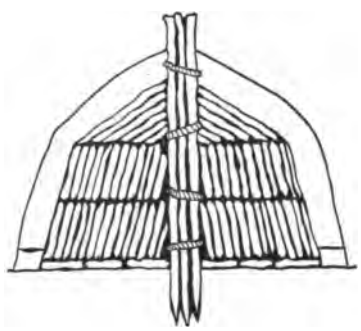


Fig. 5.

Charcoal is usually prepared by piling wood in a conical heap as shown in Fig. 5, covering it with sods and earth and letting it smoulder. Small openings are left for air. For this process a portion of the wood is burned and the rest only charred. The heat decomposes the wood, expelling the volatile gases. The product is a solid which consists mainly of charcoal.

Charcoal is a black, amorphous, porous substance, having neither taste nor odor. It is insoluble in any liquid, and cannot be melted or vaporized except in the electric furnace.

Animal charcoal is made by treating in a similar manner animal matter such as waste leather. When bones are burned, the volatile portions (water, ammonia etc.) are driven off, and the carbon is left deposited on calcium phosphate. This product is called **bone-black**, and is used in refining sugar.

Lamp-black is a nearly pure form of uncrystallized carbon. It is made by partially burning turpentine, oil, tar, resin etc., and collecting the unburned carbon or smoke.

The smoke flows into a chamber, as shown in Fig 6, where the sooty material collects on the walls and floor. It is scraped off and sold. Lamp-black is used in printers' ink, black paint, etc.

Coke is formed from soft coal. The coal is distilled upon the same principle as in wood. The process drives out the volatile gases, which are used for illuminating. Like charcoal it is very porous, but requires a high temperature to set it on fire. Coke is used for heating.

Gas Carbon is formed in the manufacture of coke and illuminating gas. It is very dense and hard.

Mineral Coal is a well-known compound of carbon. It is very abundant, being found in almost every country in the world. The United States has by far the largest amount.

Coal was once wood. It is the accumulated masses of the remains of a luxuriant vegetation of an early period of the history of our globe. Many centuries ago the earth contained vegetable life which was at least as rank as it is to-day. The earth's crust has been subject to upheaval and subsidence, which have caused the various layers to be contorted. Plant life was buried, and as time went on, it became covered with earthy matter, thus being subjected to pressure and also to a slow distillation by heat. This action of heat, pressure and percolating waters, changed the wood to coal.

Coal is found in two distinct varieties: Anthracite or hard coal, and Bituminous or soft coal.

Anthracite is rich in carbon, some varieties having about 90 per cent. It seems to have been formed from soft coal, under conditions of pressure and temperature which expelled the more volatile constituents. As anthracite coal has had most of its volatile gases expelled, it burns with little flame and will ignite only at a high temperature. It is used for heating houses, but it is more expensive than soft coal, and far less abundant.

Bituminous Coal has several sub-varieties, Cannel and Lignite. They are not as pure forms of carbon as bituminous coal. Peat is a low form of lignite or brown coal. Bituminous

coal contains less carbon than hard coal, but is richer in hydrocarbons. It gives off considerable smoke and burns with much flame at a lower temperature than anthracite, On account of the volatile gases, it is much used for making illuminating gas and coke. Cannel coal is very rich in hydrocarbons, but is very expensive.

GRAPHITE.

Graphite, also called black-lead, plumbago, etc., is a compact and comparatively pure form of carbon. It is quite abundant and widely distributed. It is found in some places as a continuation of beds of anthracite coal which thus indicates its origin. Like coal, graphite seems to come from plant life.

Graphite is a soft, black crystalline mineral, insoluble in any substance at ordinary temperatures, and is almost infusible. Graphite is a good lubricant. It is practically infusible and unlike other forms of carbon can be burned only at the highest temperatures when it forms carbon dioxide, CO_2.

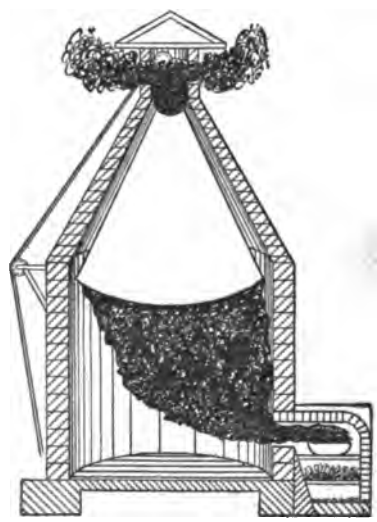


Fig. 6.

Carbon, as a graphite, is very useful. It is used as a lubricant, for facing molds for iron castings, for electrotype facings, lead pencils, stove polish and polish for gunpowder. On account of its infusibility and incombustibility, it is used for lining crucibles in which iron and steel are melted. Coal and graphite are of precisely the same chemical nature, yet while coal is burning in the fire, and thus furnishing intense heat for melting metals, the graphite, of which the crucible is made, resists heat and combustion and while allowing the metals to melt preserves them.

DIAMOND.

The diamond is nearly pure carbon crystallized. It is one of the most wonderful substances known. Diamonds are found in only a few places on the earth, and are not abundant. Since the

time of the ancient Greeks and Romans, the diamond has been prized on account of its brilliancy, rareness, hardness and unchangeability. The largest diamond ever found weighed less than half a pound, and is valued at over half a million dollars. Diamonds are cut in exact geometrical shapes as shown in Fig. 7, by splitting off portions. They are then polished by rubbing them on a revolving plate upon which is a mixture of oil and diamond dust.

Diamond is the hardest substance known with the possible exception of the artificial product, boron. There have been many attempts to make diamonds by melting carbon and then letting it crystallize. By fusing carbon with iron, minute crystals have been produced.

The principal use of diamonds is as a precious stone. Because of its hardness, it is used for cutting glass, and poor varities are used in rock drills.

OTHER FORMS OF CARBON.

In addition to the three forms of carbon already briefly described, it exists in many compounds with other elements. It is found in the atmosphere in carbon dioxide gas. Also, it is one of the important constituents of petroleum. Marble and limestone contain enormous quantities of carbon. These minerals consist largely of calcic carbonate, $CaCO_3$. Almost all animal and vegetable matter contains carbon.

USES.

The uses of carbon in the form of charcoal, graphite and diamond have already been mentioned; but some of the more important uses are worthy of discussion. On account of the infusibility, carbon is used in the pencils of arc lights. It slowly burns away, but this is expected as the current flowing from one pencil to the other gives out intense heat as well as brilliant light.

Carbon, whether as wood, charcoal or bone-black, has a wonderful power of decolorizing liquids. When colored solutions are strained through a quantity of one of these forms of carbon, the carbon absorbs the coloring matter, and the liquid that has passed through is practically colorless. On account of this property, enormous quantities of bone-black are used for whitening syrups before they are crystallized to sugar.

A similar property to this, is the power that charcoal has of absorbing offensive gases. Hence, it is used as a disinfectant. If tainted meat is packed in freshly burned charcoal, it soon loses its odor.

COMPOUNDS.

There is a large number of compounds of carbon. The reason why the number is so great is that the valence of carbon is four. We saw that the valence of hydrogen is one, and that of oxygen is one, and that there are few compounds of these two elements. Now as carbon has four hooks with which to take hold of other substances, it naturally takes hold of a great many.

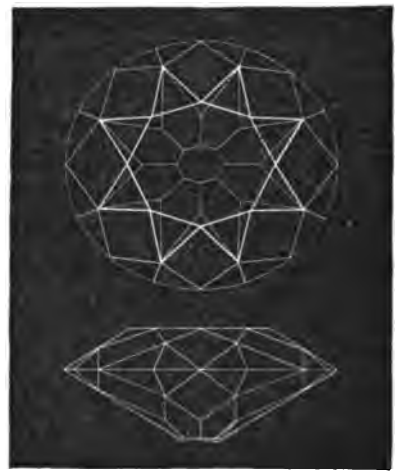


Fig. 7.

Although carbon is very inert at low temperatures, yet at high temperatures, carbon draws oxygen away from almost all known elements. It thus shows that its chemical force is superior to that possessed by any of them.

Carbon unites with oxygen forming carbon monoxide, CO, and carbon dioxide CO_2. These interesting and important compounds will be discussed with the subject Combustion, with which they are so intimately connected.

With other elements carbon forms many useful and important compounds. Many of these compounds belong to that branch of science called Organic Chemistry. Organic Chemistry was formerly considered as the chemistry of substances derived from existences that possess organs such as animals and plants. At present, however, it is considered to be the chemistry of carbon and its compounds.

This subject is of such an extent that it is impossible to discuss it here. The simple fact that organic compounds include

vegetable juices, extracts, gums, resins, essences, acids, oils, alcohols, coloring matter and many others is an indication of the extent and importance of this branch.

Most of the substances thus named are compounds of hydrogen and carbon, or of carbon, hydrogen and oxygen.

ILLUMINATING GAS.

Illuminating gas is made by two methods. If made from carbon and water, it is called *water gas;* if made by the destructive distillation of bituminous coal, it is called *coal gas.*

Water Gas.— This gas is extensively used at the present time in large cities. The process of manufacture is briefly as follows: Superheated steam is passed through red hot anthracite coal, and the gases thus formed, collected. The chemical combination may be represented by this reaction,

$$H_2O + C = CO + 2H.$$

The coal, which is contained in large cylinders (Fig. 8), is set on fire, the combustion being accelerated by a strong air blast at A. While the coal is thus burning, CO and CO_2 are formed, and the CO_2 passes off through the hood H. When the coal is burning well, or is incandescent, the air blast A is closed, as is also the top of the cylinder at C. The valve E is now opened, and the superheated steam from the boiler enters the cylinder, passes up through the burning coal, and the products CO and H (see reaction) pass out the pipe D to a reservoir. When the steam has cooled the coal, the valve E is closed, and the coal again heated.

As both H and CO burn with a feeble flame, it is necessary to mix with these some substance which will make the gas give more light. The light-giving constituents are usually the hydrocarbons obtained by distilling naphtha or petroleum.

Coal Gas.— To make this gas, cylinders called retorts made of iron or fire clay are filled with soft coal and heated to over 1000° F. by a coal fire. The gases formed pass upward through the exit pipe to the hydraulic main, which is a large pipe through which water is kept flowing. The products of distillation which pass to the hydraulic main are liquid, semi-liquid and solid (hydrogen, carbon dioxide, sulphur, ammonium compounds, coal

tar, &c); these are washed and some of them deposited in the main.

The insoluble gases pass to the condensers, which are a series of vertical pipes placed in the open air. As the gas is thus cooled, tarry liquids, which have been in the gas in the form of a vapor, are deposited.

Next the gas flows to the washers, or scrubbers, where it meets a falling spray of water which by absorbing ammonia (NH_3) and hydrogen sulphide H_2S washes the gas. It then goes to the purifiers, which are large iron boxes with a large number of shelves on which is dry quicklime, CaO, or hydrated ferric oxide. The quicklime absorbs H_2S and other acid gases. The gas is now pure enough for use, and passes into the large tanks called gas holders from which it goes to the consumers.

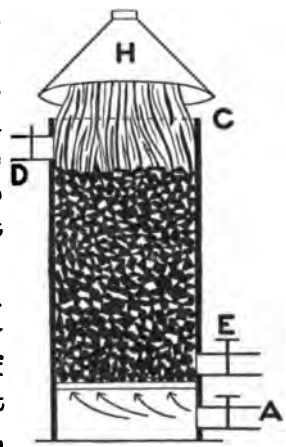


Fig. 8.

Composition. — When coal distilled gas is in its purest condition, it is a very complex substance and the proportions of the constituents vary somewhat. About 5 per cent. is made up of hydrocarbons, such as C_2H_2, C_6H_6, C_2H_4, &c. These hydrocarbons are the light-giving portions. Impurities, such as CO_2 and N make up about 5 per cent. more. The remaining 90 per cent. is made up of three gases which give but little light. These are H about 45 per cent., CH_4 about 40 per cent., and CO about 5 per cent.

Products. — There are three distinct classes of products of the distillation of coal; solids, liquids and gases. The solids are left in the retorts, the liquids are condensed in the coolers, and the gases are absorbed by quicklime and water, and pass to the gas-holder.

The **solids** are coke and gas carbon. Coke, the spongy substance left in the retort, is a form of carbon. It is used as a fuel. The **gas carbon** is a sort of scale, and is used for the carbons for electric lights.

The **liquids** consist of complicated mixtures of carbon com-

pounds, but they are of great interest and importance. When coal gas was first made, these liquid products were thrown away, but little by little chemists began to recognize their value, and now they are very useful in the arts. From the filthy and offensive coal-tar, the most beautiful and brilliant dye-stuffs are made. These dyes are very permanent. One of the substances from coal-tar is benzole, a compound C_6H_6, from which the well-known aniline dyes are produced. The preparation of these dyes from the apparently worthless product, coal-tar, is a great achievement.

The gaseous products. — The gases generated in the process of coal-gas manufacture are numerous. Some are combustible, but have little illuminating power, such as hydrogen and carbon monoxide. Others, ethylene (C_2H_4), for instance, have high illuminating power. Nitrogen is always formed, but contributes nothing to the value of the gas. The sulphur compounds, H_2S, etc., burn, but form undesirable oxides of sulphur.

COMBUSTION.

Combustion is a rapid chemical combination of the substance that burns, and the substance that supports combustion. It is usually attended with light, and always with heat.

The two principal substances that burn are carbon and hydrogen, or their compounds; the supporter of combustion is oxygen. In addition to the two substances (the one that burns and the supporter), another condition is necessary — a temperature sufficiently high for the union of the substances.

If a stove is partly filled with wood or coal (both contain carbon and hydrogen), and the doors opened, the substances will not burn, although there is plenty of oxygen surrounding the lumps of coal, If, however, the temperature of the coal is raised sufficiently high, the wood or coal burns; or, chemical union takes place.

In order to have carbon, hydrogen or sulphur burn, they must be set on fire or kindled. In other words, the temperature of the substance must be raised to a certain degree before it will burn. This is called the kindling point, and the kindling point varies for different substances.

Flame indicates the combustion of a liquid or gas. Solids simply glow when burning, but do not give out flame.

Coal, the principal fuel used in engineering, is composed chiefly of carbon, the amount varying from about 50 per cent. to 85 per cent. In addition to carbon, coal contains compounds of hydrogen and carbon, called hydrocarbons. These are gases which burn with both light and heat. The third constituent of coal is called ash. It is an earthy substance which remains after the burning of the coal.

As already stated, combustion is a rapid chemical combination of oxygen with carbon and hydrocarbons. Oxygen and carbon have a very strong attraction for each other at high temperatures, and unite with great force, producing light and heat.

When coal is first thrown on the fire or placed on the dead plate, the heat from the fire drives off the hydrocarbons. These gases, being combustible, are burned above the fire or, as in the case of a marine boiler, in the combustion chamber. In order to have the hydrocarbons burn, enough oxygen must be admitted to unite with them, and the temperature must be sufficiently high. If these hydrocarbons do not burn, because of low temperature or of insufficient oxygen, they pass up the chimney and a large amount of available heat is lost.

After the hydrocarbons are driven off, the solid portion, coke, is left on the grate or dead plate. To burn the coke, air (containing oxygen) passes up between the grate bars and through the spaces between the pieces of coal.

In burning both hydrocarbons and carbon, or coke, certain new substances are formed, which are called products of combustion. These are gases, carbon dioxide, CO_2, carbon monoxide, CO and water, H_2O (as a vapor).

If there is plenty of oxygen present when hydrocarbons and carbon are burned, the products are CO_2 and H_2O. If there is insufficient oxygen, the products are CO and H_2O.

CARBON DIOXIDE.

This important and interesting gas is called carbon dioxide, carbonic acid, carbonic acid gas and carbonic anhydrid. Its im-

portance and effect on animal and plant life have already been mentioned. The principal natural source in the atmosphere is the combustion of fuel. The gas is made up of carbon and oxygen, and as coal, wood, oil, illuminating gas, etc., are all carbonaceous substances this gas is formed whenever combustion takes place.

Carbon dioxide occurs combined in all carbonates; limestone, $CaCO_3$, being the most abundant.

To prepare carbon dioxide it is only necessary to cause some acid, as hydrochloric acid, to act on a carbonate, as calcium carbonate, $CaCO_3$. The gas thus liberated can be collected and used to ascertain its properties. The action of the acid on the carbonate may be expressed as follows:

$$CaCO_3 + 2\ HCl = CaCl_2 + H_2CO_3.$$

The H_2CO_3 (carbonic acid) is very unstable and breaks up almost as soon as formed into CO_2 and H_2O.

$$H_2CO_3 = H_2O + CO_2.$$

Carbon dioxide is formed whenever carbon burns with plenty of oxygen

$$C + 2O = CO_2.$$

Carbon dioxide is a heavy colorless gas with a pungent ordor. On account of its weight, it does not mix readily with other gases or the air, but collects in the bottoms of wells and near the floors in rooms. CO_2 does not support combustion, nor is it a supporter of respiration.

Formerly it was thought that carbon dioxide was poisonous, but it is now thought that CO_2 causes death by excluding oxygen. The fact that carbon dioxide is beneficial to the system if taken into the stomach shows that it is not poisonous.

CO_2 is somewhat soluble in water, and when dissolved in water forms with it a weak, unstable acid, H_2CO_3.

The principal uses of carbon dioxide are as follows: It is used in making soda-water and artificial mineral water. Soda-water is simply water in which considerable CO_2 is dissolved; carbon dioxide being soluble in water. It is also used in chemical engines, because it does not support combustion. When H_2SO_4 unites with sodium carbonate Na_2CO_3, carbon dioxide is formed.

$$H_2SO_4 + Na_2CO_3 = H_2CO_3 + Na_2SO_4.$$

The carbonic acid, H_2CO_3, immediately breaks up into H_2O and CO_2.

The action of yeast in bread-raising is a kind of fermentation; the carbon dioxide and alcohol formed cause the dough to raise and make the bread porous.

CARBON MONOXIDE.

Carbon monoxide is not nearly as common as carbon dioxide. The reason is that the compound CO contains only one-half as much oxygen as does CO_2 and as it is only half saturated, it has a great affinity for oxygen. On account of the activity of CO, it readily combines with oxygen and other elements.

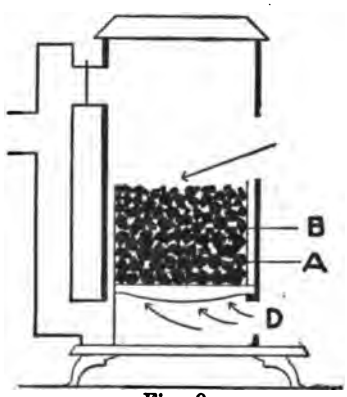


Fig. 9.

This gas, carbon monoxide, does not occur naturally anywhere, except in case of combustion in a limited amount of air. It forms one of the principal constituents of water gas.

Carbonic oxide is a colorless gas without taste and with but little odor. Its chief property is its poisonous nature. It is the deadly constituent of water gas.

As has already been stated, carbon dioxide is formed when combustion is carried on with an abundance of oxygen, and carbon monoxide when the supply of oxygen is limited. In this connection let us consider the ordinary coal stove, (Fig. 9). Air, containing oxygen, enters through the lower door D, and since there is plenty of oxygen, CO_2 is formed in the zone represented at A.

$$C + 2O = CO_2$$

As this carbon dioxide rises through the hot coal, where there is but little oxygen, it gives up one-half of its oxygen to the carbon of the coal, and carbon monoxide is formed in zone B.

$$CO_2 + C = 2CO.$$

When the gas, CO, reaches the surface of the coal, where it meets the oxygen which has entered the draft plate or grid in the upper door, it is changed to CO_2.

$$CO + O = CO_2$$

There is one great difference between carbon dioxide and carbon monoxide that is of importance to the engineer. CO_2 is not combustible while CO can be burned. Let us see how this fact affects the economy of a boiler.

If the air supply is not sufficient to form carbon dioxide, carbon monoxide, CO, is the product. This gas is combustible, and as it will give up considerable heat, if burned, it is undesirable to have it pass unburned up the chimney. This loss is prevented by burning the coal with more oxygen.

We thus see the necessity of admitting sufficient air to the coal, if we wish to run our boiler economically. However, we cannot open the doors and let in an unlimited supply of air, because too much air is a source of loss, as we shall see later. How then are we to know how much air to admit? While the fireman is shovelling coal and regulating the dampers, he cannot stop to figure out the amount of air he should use or is using, but he judges the right amount from the appearance of his fire, and the smoke that issues from the chimney.

By knowing a few principles of chemistry, and the chemical composition of the coal, we can calculate the amount of air theoretically necessary to burn the coal economically.

AMOUNT OF AIR NECESSARY TO BURN FUEL.

Air is composed of about 77 per cent. of nitrogen and argon, and 23 per cent. of oxygen. The oxygen is the only element that aids combustion; therefore, if one pound of air is admitted to the ashpit, only about one-fourth of a pound of oxygen aids combustion; the three-fourths of a pound of nitrogen is inert. The nitrogen is of no aid, but is a source of loss because it must be heated to the same temperature as that of the oxygen. For every pound of air admitted in excess of the amount necessary, three-fourths of a pound of nitrogen takes heat from the coal. Thus we see that the regulation of the air supply is exceedingly important.

If the proper amount of air is admitted, the hydrocarbons and carbon are burned, forming water (in the form of steam) and carbon dioxide. These gases, the products of combustion, together with heated nitrogen and smoke, pass up the chimney.

Carbon Dioxide.

We have already learned that the product obtained by burning carbon in oxygen is carbon dioxide gas, CO_2. This gas is composed of 12 parts carbon and 32 parts oxygen.

$$C = 12,\ O_2 = 2 \times 16 = 32.$$

Now, since 32 parts are oxygen and 12 parts are carbon, $\frac{32}{12}$ pounds of oxygen are necessary in burning one pound of carbon. In other words, for every pound of carbon that is burned in the furnace, $\frac{32}{12} = 2\frac{2}{3} = 2.67$ pounds of oxygen must be supplied to obtain the product CO_2. Air contains but 23 per cent. of oxygen; then to obtain 2.67 pounds of oxygen from the air, $2.67 \div .23 = 11.6$ pounds must be used.

We have said that 11.6 pounds of air furnishes 2.67 pounds of oxygen. It is evident that the remainder is nitrogen; or $11.6 - 2.67 = 8.93$ pounds of nitrogen are also obtained. Thus if one pound of carbon is burned in 11.6 pounds of air, the products are one pound of carbon, 2.67 pounds of oxygen (making 3.67 pounds of CO_2) and 8.93 pounds of nitrogen.

1 lb. C + 2.67 lbs. O + 8.93 lbs. N = 12.6 lbs.

This is the manner in which the 11.6 pounds of air and 1 pound of carbon unite.

We may say in brief that *to completely burn one pound of carbon we must use 11.6 pounds of air. From this 2.67 pounds of oxygen are used in combustion and 8.93 pounds of nitrogen pass up the chimney without aiding combustion.*

Water.

The product obtained by burning carbon is carbon dioxide; if hydrogen is burned, the product is water, H_2O. We know that water is 2 parts hydrogen and 16 parts oxygen.

$$H = 1,\ H_2 = 2,\ O = 16.$$

Then one pound of hydrogen requires $\frac{16}{2} = 8$ pounds of oxygen. To obtain 8 pounds of oxygen, 34.8 pounds of air are

necessary, because air contains 23 per cent. oxygen and 8 ÷ .23 = 34.8.

If one pound of hydrogen is burned in air, 34.8 pounds of air will be required, and we will get as products 8 pounds of oxygen and 1 pound of hydrogen (making 9 pounds of water) and 34.8 — 8 = 26.8 pounds of nitrogen.

1 lb. H + 8 lbs. O + 26.8 lbs. N = 35.8 lbs.

To completely burn one pound of hydrogen, we must use 34.8 pounds of air. Of this 8 pounds of oxygen are used in combustion, and 26.8 pounds of nitrogen pass up the chimney without aiding combustion.

Carbon Monoxide.

If the combustion is not complete, the product is CO instead of CO_2. We see that this is so because in equal amounts of CO and CO_2, there is but one-half as much oxygen in the former as in the latter. As there is only one-half as much oxygen in CO as in CO_2, it takes only one-half as much oxygen to burn carbon to CO as it does to CO_2. We know that 11.6 pounds of air are necessary to burn carbon to CO_2; therefore to burn it to CO only $\frac{11.6}{2}$ = 5.8 pounds of air are necessary.

If one pound of carbon is burned to CO, 5.8 pounds of air are necessary. Of this 5.8 pounds of air, 1.33 pounds of oxygen are used in combustion, and 4.47 pounds of nitrogen pass up the chimney.

The quantities of air required for combustion are as follows:

To burn one pound of

Carbon to CO_2 requires 11.6 pounds of air.
Carbon to CO requires 5.8 pounds of air.
Hydrogen to H_2O requires 34.8 pounds of air.

Coal is composed of hydrogen, carbon and a small amount of incombustible matter.

From the above we can calculate how much air is theoretically necessary to burn a pound of coal, if we know the amount of carbon and hydrogen in the coal.

Suppose we have a coal composed of the following;

Carbon, 85 per cent.
Hydrogen, 10 per cent.
Ash, 5 per cent.

Since it takes 11.6 pounds of air to burn 1 pound of carbon to CO_2, it would take $11.6 \times .85 = 9.86$ pounds of air to burn the carbon in 1 pound of coal.

To burn the hydrogen, 3.48 pounds of air are necessary because 34.8 pounds are necessary to burn 1 pound and $34.8 \times .10 = 3.48$.

Hence, it takes $9.86 + 3.48 = 13.34$ pounds of air to burn one pound of coal of the above composition.

To find the amount of air theoretically necessary to burn one pound of any fuel, we find the amount required to burn the carbon by multiplying the percentage of carbon by 11.6, and the amount required to burn the hydrogen by multiplying the percentage of hydrogen by 34.8. The sum of these two results is the desired quantity.

EXAMPLES FOR PRACTICE.

1. How much air will be required for the perfect combustion of 12 pounds of carbon? Ans. 139.2 pounds.

2. How many pounds of air will be required to burn .4 pound of hydrogen? Ans. 13.92 pounds.

3. A certain kind of coal contains 87 per cent. of carbon, 8 per cent. of hydrogen, and 5 per cent. ash. How many pounds of air will be required to burn one ton (2000 pounds)?

Ans. 25,752 pounds.

HEAT OF COMBUSTION.

Combustion always produces heat. In order to know how much coal must be burned to convert a given quantity of water into steam we must know how much heat the coal will give out per pound. To ascertain this amount, we must have some means of measuring heat.

Heat is measured in British thermal units usually abbreviated thus, B. T. U.

A British thermal unit is the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit. Experiment shows that the amount of heat necessary to raise the temperature of 1 pound of water 5 degrees is 5 B. T. U. Also 5 B. T. U. will raise the temperature of 5 pounds of water 1 degree.

Now, if we burn one pound of hydrogen and measure the heat given out, we find it to be 62,000 B. T. U. That is, sufficient heat is given out in burning one pound of hydrogen to raise 62,000 pounds of water one degree; or it will raise 3,100 pounds of water 20 degrees, because $3{,}100 \times 20 = 62{,}000$.

Carefully conducted experiments show the following:

The heat produced in burning;

Hydrogen = 62,000 B. T. U. per pound.
Carbon to CO_2 = 14,500 B. T. U. per pound.
Carbon to CO = 4,400 B. T. U. per pound.

Knowing these facts, we can now ascertain how much heat will be evolved in completely burning a pound of coal.

An analysis of a certain kind of coal is as follows:

Hydrogen 5 per cent.
Carbon 79 per cent.
Ash 12 per cent.

Since 5 per cent. of the coal is hydrogen, there is .05 pound of hydrogen in a pound of coal. We know that if one pound of hydrogen is burned, the heat given up will equal 62,000 B. T. U. Then, if .05 is burned, $.05 \times 62{,}000 = 3{,}100$ B. T. U. will be produced. Similarly if .79 pound of carbon is burned, $.79 \times 14{,}500 = 11{,}455$ B. T. U. will be evolved. Or,

$.05 \times 62{,}000 = 3{,}100$ B. T. U.
$.79 \times 14{,}500 = 11{,}455$ B. T. U.

14,555 B. T. U.

In order to know how much water 14,555 B. T. U. will evaporate, we must know how much heat is necessary to convert water into steam. Suppose the water enters the boiler at 212° F. In order to convert one pound into steam, 966 B. T. U. must enter the water. Then the 14,555 B. T. U. will evaporate

$$\frac{14{,}555}{966} = 15.06 \text{ pounds.}$$

To find the number of pounds of water which 1 pound of coal will evaporate into steam (water being at 212° F.), divide the heat value of the coal by 966. This number 966 is called the latent heat or heat of vaporization.

Boilers are seldom supplied with water at 212°. Suppose in

the above case, the water had been at 32° instead of 212°, how much water would one pound of the fuel evaporate? Before the water can be converted into steam, its temperature must be raised from 32° to 212°. This will require 212 — 32 = 180 B. T. U., since it requires one B. T. U. to raise one pound of water one degree. Then if it takes 180 B. T. U. to raise the water to 212° and 966 B. T. U. to convert it into steam after it has been raised to 212° the total amount of heat necessary per pound would be 180 + 966 = 1146. Then if the coal has a heat value of 14,555, it would theoretically evaporate,

$$\frac{14{,}555}{1146} = 12.7 \text{ pounds.}$$

Thus heating the feed water from 32° F. to 212° F. enables one pound of this coal to evaporate 15.06 — 12.70 = 2.36 more pounds of water.

These figures are higher than those found in actual practice because some heat is lost in radiation, conduction, etc.

The figures 966 and 1146 are found in the table on page 62.

EXAMPLES FOR PRACTICE.

1. A coal has the following composition: H, 6 per cent., C, 81 per cent., O, 3.5 per cent., N, 1 per cent., and ash 8.5 per cent. (a) What is the heat value per pound? (b) How much water will one pound evaporate?

Ans. (a) 15,465 B. T. U., (b) 16 pounds.

2. If water enters a boiler at 32° F. and is converted into steam at 212° F., how many heat units will theoretically be required to evaporate 6 pounds of water? Ans. 6,876 B. T. U.

3. A coal contains 80 per cent. carbon and 5 per cent. hydrogen. (a) How many B. T. U. would be given out by the combustion of one pound? (b) How many pounds of water would 5 pounds of this fuel evaporate from and at 212° F.?

Ans. (a) 14,700 B. T. U. (b) 76 pounds.

*TEMPERATURE OF COMBUSTION.

In order to have heat flow from the fire through the plates of a boiler to the water, it is necessary to have the temperature of the fire greater than that of the water. The flow of heat through

*NOTE: The following discussion (pages 51-59) may be omitted if the student desires, but it should be read over carefully.

a plate is proportional to the difference in temperature of the sides. That is, if the water is 100°, the higher the temperature of the fire, the greater will be the flow of heat. In practice the temperature of the water does not vary much, hence a great difference of temperature is obtained by having a high temperature in the furnace.

In order to calculate the theoretical temperature in a furnace, latent heat, specific heat and the British thermal unit must be thoroughly understood.

Latent Heat. — If we apply heat to water, the temperature of the water rises. It continues to rise until (if under atmospheric pressure) it reaches 212° Fahrenheit. At 212° F. the addition of heat causes the water to change its physical condition, but does not cause any rise of temperature. This change is from liquid to gas, or from water to steam. While water is changing from water to steam, it absorbs a large amount of heat, and this heat is called latent or hidden, because the water absorbs it without any change of temperature.

Latent heat is the heat that must be given to a body to change its condition without changing its temperature.

On page 51 we found that to raise the temperature of a pound of water from 32° to 212° required 180 B. T. U., and that to change the water at 212° to steam at the same temperature required 966 B. T. U. The 966 B. T. U. is the latent heat of water.

Specific Heat. — We know that the amount of heat necessary to raise one pound of water one degree is one thermal unit. It is a well-known fact that one thermal unit is more than sufficient to raise the temperature of one pound of any other substance (except hydrogen) one degree. In other words, if the temperatures of equal weights of different elements are raised the same number of degrees, they take up different quantities of heat. Different substances have different capacities for heat.

For example, the amount of heat required to raise the temperature of one pound of water one degree is 31 times as great as that needed to raise the temperature of one pound of platinum one degree. Or, one British thermal unit will raise 31 pounds of platinum 1 degree, or will raise one pound of platinum 31 degrees.

The specific heat of a body is the ratio of the quantity of heat necessary to raise its temperature one degree to the amount of heat necessary to raise the temperature of the same weight of water one degree.

Carefully conducted experiments have determined the specific heat of various substances, a few of which are given in the following table:

SPECIFIC HEAT.

Hydrogen	3.4090	Carbon dioxide	.2170
Water	1.0000	Cast Iron	.1298
Steam	.4805	Wrought Iron	.1138
Air	.2375	Steel (hard)	.1175
Oxygen	.2175	Steel (soft)	.1165
Nitrogen	.2438	Copper	.0951
Carbon monoxide	.2479	Sulphur	.2026

The British Thermal unit has already been defined as being *the amount of heat required to raise the temperature of one pound of water one degree.*

From the above definition we see that pounds of water multiplied by degrees Fahrenheit, gives British thermal units. In other words, British thermal units *divided* by pounds of water gives temperatures in degrees Fahrenheit. This is the principle upon which the calculation of furnace temperature is based.

When one pound of hydrogen is burned, 62,000 B. T. U. are given off. All of this heat is not available for heating water, because when hydrogen is burned, water is formed as a product, and this water is converted into steam in the furnace.

Suppose 1 pound of hydrogen is burned; 9 pounds of water are formed, since one pound of hydrogen unites with 8 pounds of oxygen to form water. Now this water (9 pounds) is changed to steam, and in changing from water to steam it will absorb $9 \times 966 = 8{,}694$ B. T. U. Then the available heat is $62{,}000 - 8{,}694 = 53{,}306$ B. T. U.

We know that temperature equals B. T. U. divided by pounds of water. In this case we have the water in the form of steam, but we can reduce it to pounds of water by multiplying by

its specific heat. Then we may say that 9 pounds of steam are equivalent to $9 \times .4805 = 4.3245$ pounds of water.

We can now find the temperature.

$$\text{Temperature} = \frac{\text{B. T. U.}}{\text{pounds of water}}$$

$$\text{Temperature} = \frac{53{,}306}{4.3245}$$

$$\text{Temperature} = 12{,}326° \text{ F.}$$

Therefore the theoretical temperature due to burning one pound of hydrogen is 12,326 degrees.

Let us also consider carbon, since coal is composed chiefly of hydrogen and carbon.

If carbon is burned to CO_2 the amount of heat given up is 14,500 B. T. U. As no water is formed when carbon is burned, it is not necessary to subtract any heat. When 1 pound of carbon is burned to CO_2 the product is 3.67 pounds of CO_2, because 1 pound of carbon unites with 2.67 pounds of oxygen to form CO_2.

The specific heat of CO_2 is .2170 (from the table). Then 3.67 pounds of CO_2 are equivalent to $3.67 \times .2170 = .7964$ pounds of water. Now since the B. T. U. are 14,500 and the amount of water is .7964 pounds, we can find the theoretical temperature as follows:

$$\text{Temperature} = \frac{\text{B. T. U.}}{\text{pounds of water}}$$

$$\text{Temperature} = \frac{14{,}500}{.7964}$$

$$\text{Temperature} = 18{,}206°\text{F.}$$

These temperatures are theoretical for the burning of hydrogen and carbon in oxygen; they will be much reduced if we make the calculation allowing for the heat absorbed by the nitrogen.

Since nitrogen has no part in forming water, there is nothing to subtract from the available heat. But heat enters the nitrogen, and as we know its specific heat we can find its water equivalent.

In connection with the amount of air theoretically necessary to burn fuel, we found that 34.8 pounds of air were necessary to

furnish sufficient oxygen to burn 1 pound of hydrogen. Of this 34.8 pounds of air, 26.8 is nitrogen. This nitrogen must be raised to the same temperature as that of the hydrogen. Since the specific heat of nitrogen is .2438, the amount of heat required to raise one pound of nitrogen one degree is .2438 B. T. U., and the amount necessary to raise 26.8 pounds of nitrogen one degree is $26.8 \times .2438 = 6.534$ B. T. U.

To find the available heat when hydrogen is burned, we subtract the heat made latent by the steam from 62,000 B. T. U. Or $62{,}000 - (9 \times 966) = 53{,}306$ B. T. U.

The number of pounds of water is the sum of the water equivalent to the steam and of the nitrogen. This is equal to $(9 \times .4805) + (26.8 \times .2438) = 10.8583$.

From the definition of B. T. U. we have the following:

$$\text{Temperature} = \frac{\text{B. T. U.}}{\text{pounds of water}}$$

$$= \frac{53{,}306}{(9 \times .4805) + (26.8 \times .2438)}$$

$$= 4{,}909^\circ \text{ F.}$$

To find the temperature from burning carbon, we proceed in the same manner.

The heat of combustion of 1 pound of carbon to CO_2 is 14,500 B. T. U.

The number of pounds of water which is equivalent to the number of pounds of CO_2 and nitrogen raised to the temperature of the carbon is as follows:

To burn 1 pound of carbon to CO_2, 11.6 pounds of air are necessary of which 8.93 pounds are nitrogen. The heat required to raise one pound of nitrogen one degree is .2438 B. T. U. Then the amount of heat necessary to raise 8.93 pounds of nitrogen one degree is $8.93 \times .2438 = 2.177$ B. T. U. We also know that when carbon is burned to CO_2, 2.67 pounds of oxygen unite with one pound of carbon and form 3.67 pounds of CO_2. Since the specific heat of CO_2 is .217, the water equivalent of the CO_2 is $3.67 \times .217 = .796$ pounds.

The total water equivalent is the sum of these two, or $2.177 + .796 = 2.973$.

The temperature is found as follows:

$$\text{Temperature} = \frac{\text{B. T. U.}}{\text{pounds of water}}$$

$$= \frac{14{,}500}{(8.93 \times .2438) + (3.67 \times .217)}$$

$$= 4{,}877°.$$

Thus we have found the temperature to be 4,909° when hydrogen is burned, and 4,877° when carbon is burned. This calculation does not allow for air of dilution; it is made on the basis that just sufficient air is admitted to completely burn the substances.

It is evident that if twice or three times as much air is admitted as is necessary, the temperature will be reduced because of the heat required to raise the temperature of the large quantity of nitrogen.

Let us take an example. Suppose we have a coal of the following composition:

Carbon	90 per cent.
Hydrogen	5 per cent.
Ash	5 per cent.

Let us first find the temperature if just sufficient air is used.

Heat of combustion — Since one pound of carbon gives up 14,500 B. T. U., .9 of a pound will produce $14{,}500 \times .9 = 13{,}050$ B. T. U.

In burning one pound of hydrogen, 62,000 B. T. U. are given out; in burning .05 of a pound, $.05 \times 62{,}000 = 3{,}100$ B. T. U. will be evolved. Then the total B. T. U. will be $13{,}050 + 3{,}100 = 16{,}150$.

As some hydrogen is burned, steam is formed. Let us see how much. We know that one pound of hydrogen unites with 8 pounds of oxygen to form 9 pounds of water. Then .05 of a pound of hydrogen will unite with $8 \times .05 = .4$ of a pound of oxygen to form $.4 + .05 = .45$ of a pound of water. As the latent heat of 1 pound of water is 966 B. T. U., that of .45 of a pound would be $.45 \times 966 = 434.7$. As this must be subtracted from the heat produced, the available heat will be $16{,}150 - 434.7 = 15{,}715.3$ B. T. U.

We may write this as follows:

Heat of combustion of .9 of a pound of C, .9 × 14,500 = 13,050 B. T. U.

Heat of combustion of .05 of a pound of H, .05 × 62,000 = 3,100 B. T. U.

Total heat of combustion, 16,150 B. T. U.

Heat becoming latent, .45 × 966 = 434.7 B. T. U.

Available B. T. U., 16,050 — 434.7 = 15,715.3.

Water equivalent of gases. — One pound of carbon with 2.67 pounds of oxygen forms 3.67 pounds of CO_2. The .9 of a pound of carbon will unite with .9 × 2.67 = 2.403 pounds of oxygen, forming 2.403 + .9 = 3.303 pounds of CO_2. The specific heat of CO_2 is .217. Then the water equivalent of the CO_2 = 3.303 × .217 = .7167.

The .05 of a pound of hydrogen unites with .4 of a pound of oxygen and forms .45 of a pound of steam. The water equivalent of the steam is .45 × .4805 = .2162.

When the carbon burns, .9 × 11.6 = 10.44 pounds of air are supplied and, and as 2.403 pounds are oxygen, then 10.44 — 2.403 = 8.037 pounds are nitrogen. When the hydrogen burns, .05 × 34.8 = 1.74 pounds of air are admitted, and since .4 of a pound is oxygen (which unites with the hydrogen to form water) 1.74 — .4 = 1.34 pounds are nitrogen.

Then the total amount of nitrogen is 8.037 + 1.34 = 9.377. The specific heat of nitrogen is .2438, hence the water equivalent of the nitrogen is 9.377 × .2438 = 2.2861.

The total water equivalent is the sum of .7167 (CO_2) + .2162 (H_2O) + 2.2861 (N) = 3.2190.

We may tabulate these results as follows:

Water equivalent of steam = .45 × .4805 = .2162.

Water equivalent of CO_2 = 3. 303 × .217 = .7167.

Water equivalent of N = 9.377 × .2438 = 2.2861.

Total water equivalent of gases = 3.2190.

The temperature can now be calculated.

$$\text{Temperature} = \frac{\text{B. T. U.}}{\text{pounds of water.}}$$

$$\text{Temperature} = \frac{15{,}715.3}{3.2190}$$

$$\text{Temperature} = 4{,}882°$$

In practice, more air is admitted than is theoretically necessary, because considerable air must be admitted to force its way among the lumps of coal; and because it is more economical to admit too much air than too little. The fireman cannot of course tell just how much in pounds or cubic feet is entering the ashpit.

Let us see how the above temperature will be altered if $1\frac{1}{2}$ times as much air is admitted as is theoretically necessary.

From page 49 we know that to find the amount of air theoretically necessary to burn a pound of fuel, we find the weight required to burn the carbon by multiplying the percentage of carbon by 11.6, and the amount of air required to burn the hydrogen by multiplying the percentage of hydrogen by 34.8. The sum of these two results is the total weight of air.

Then for the coal under consideration,

$$.9 \times 11.6 = 10.44 \text{ pounds.}$$
$$.05 \times 34.8 = 1.74 \text{ pounds.}$$

Total = 12.18 pounds.

If 12.18 pounds of air are theoretically necessary, and $1\frac{1}{2}$ times this amount enters the ashpit, the surplus air is 6.09 pounds. Since the specific heat of air is .2375, the water equivalent of the surplus air is $.2375 \times 6.09 = 1.4463$.

The water equivalent of the gases, if the necessary amount of air is admitted, is 3.2190. Under these conditions, the total water equivalent is $3.2190 + 1.4463 = 4.6653$.

As all of the hydrogen is burned without the surplus air, no more water is formed and the available B. T. U. is unchanged.

Since the B. T. U. is 15,715.3, the

$$\text{Temperature} = \frac{\text{B. T. U.}}{\text{pounds of water.}}$$
$$\text{Temperature} = \frac{15{,}715.3}{4.6653}$$
$$\text{Temperature} = 3{,}368°.$$

This shows us that by admitting the surplus air, the calculated temperature drops $4{,}882 - 3{,}368 = 1{,}514$ degrees.

If twice as much air is admitted as is theoretically necessary, there will be a surplus of 12.18 pounds. The water equivalent of 12.18 pounds of air is $12.18 \times .2375 = 2.8927$

Then the temperature will be

$$\frac{15{,}715.3}{2.8927 + 3.2190} = 2571°$$

Or, if we admit twice as much air as is theoretically necessary, we get a drop of 4,882 — 2,571 = 2,311 degrees.

These calculations show how very important is the regulation of the amount of air to the ashpit.

Let us consider these problems algebraically.

First: — *To find the air required to burn a given fuel.*

Let Y = the number of cubic feet of air.
X = number of pounds of air.
C = the percentage of carbon in the coal.
H = the percentage of hydrogen in the coal.

$$\text{Then } X = 11.6 \times \frac{C}{100} + 34.8 \times \frac{H}{100}$$
$$= .116\ (C + 3H)$$
$$Y = 152 \times \frac{C}{100} + 457 \times \frac{H}{100}$$
$$= 1.52\ (C + 3H) \text{ nearly.}$$

Expressed in words these equations are: To find the air at ordinary temperature required to completely burn one pound of a given fuel, add the percentage of carbon to 3 times the percentage of hydrogen and multiply the sum by .116 to get the weight, and by 1.52 to get the volume.

Second. — *To find the heat of combustion in one pound of fuel.*

Let B = the B. T. U. produced by combustion.
C = percentage of carbon in the coal.
H = percentage of hydrogen in the coal.

$$\text{Then } B = 14{,}500 \frac{C}{100} + 62{,}000 \frac{H}{100}$$
$$= 145C + 620H.$$
$$= 145\ (C + 4.276H)$$

To find the heat of combustion in B. T. U. add 4.276 times the percentage of hydrogen to the percentage of carbon and multiply the sum by 145. Or, multiply the percentage of carbon by 145 and the percentage of hydrogen by 620 and add the results.

To find the number of pounds of water at 212° F. that will

be evaporated by a pound of a given fuel, divide the heat of combustion in B. T. U. by 966.

Let W = pounds of water.

B = heat of combustion in B. T. U.

Then $W = \frac{B}{966}$

Third.— *To find the temperature of combustion.*

To find the heat of combustion, multiply the weight of the carbon by 14,500, and the weight of hydrogen by 62,000.

To find the latent heat of the steam, multiply the weight of steam by 966.

To find the weight of steam, multiply the amount of hydrogen by 8 and add to it the amount of hydrogen.

To find the weight of CO_2, multiply the amount of carbon by 2.67 and add the amount of carbon.

To find the weight of nitrogen, multiply 26.8 by the amount of hydrogen, and 8.93 by the amount of carbon and add these products. To find the equivalent in water of the amounts of the products of combustion and nitrogen, multiply the weights of the substances by the specific heats as given in the table.

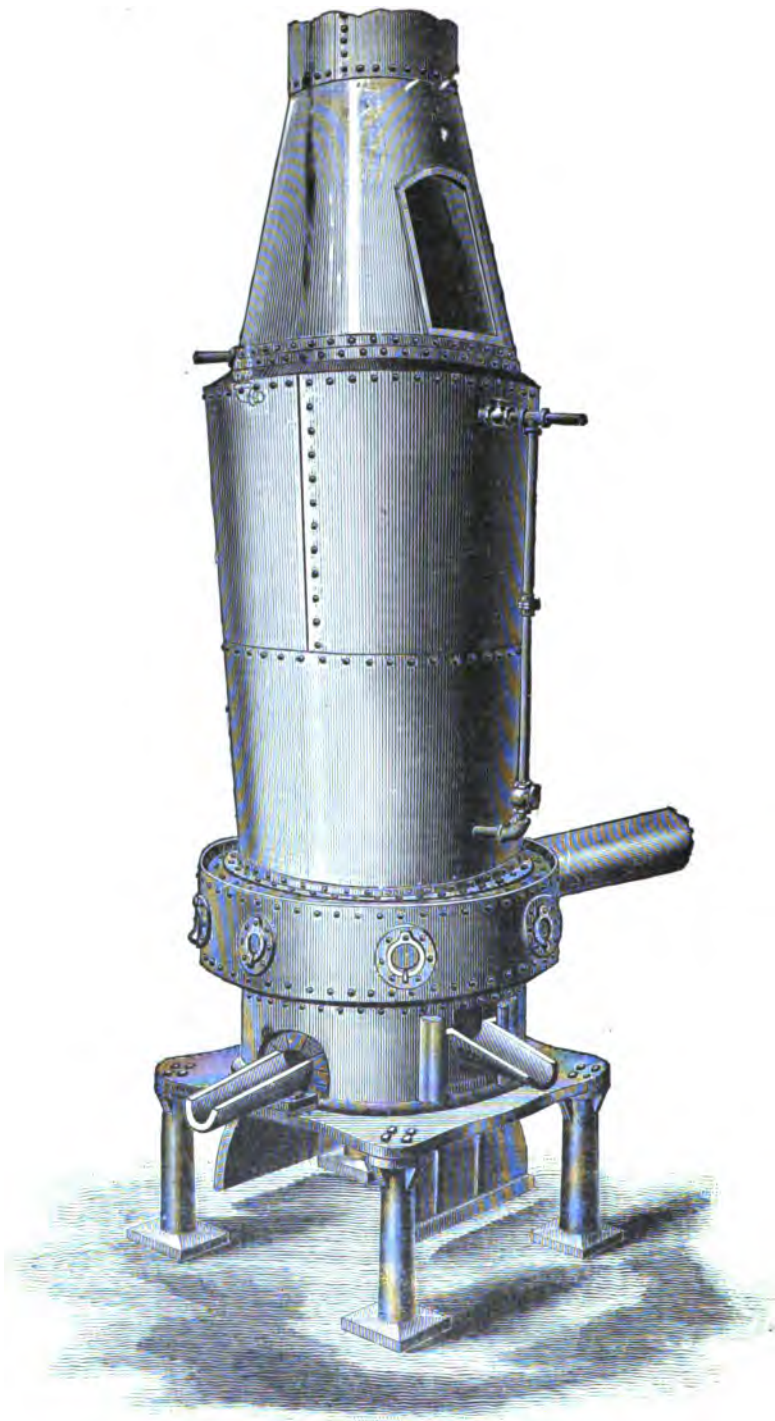
To find the temperature, add together the heat of combustion of the carbon and hydrogen, and then subtract the latent heat of the steam; divide the result by the water equivalent. The result is temperature in degrees Fahrenheit.

If there is more than the necessary amount of air admitted, find the water equivalent of the surplus air, and add it to the total water equivalent of the products and nitrogen; divide the total available B. T. U. by this new water equivalent and the result will be the desired temperature.

EXAMPLE FOR PRACTICE.

1. A fuel contains 80 per cent. carbon, 7 per cent. hydrogen and 13 per cent. ash, &c. Find the temperature of the furnace (*a*) when the amount of air admitted is that theoretically necessary to completely burn the fuel; (*b*) when the surplus air is 50 per cent. and (*c*) when the surplus air is 75 per cent.

Ans. (*a*) 4884°, (*b*) 3384°, (*c*) 2934°.



STEEL WATER-JACKETED BLAST FURNACE FOR COPPER ORES
ROUND TYPE
Allis-Chalmers Company

SECTION 2.

METALLURGY.

IRON.

For centuries iron has been the most useful metal known to man. In the earliest periods of history, stone implements were used; later bronze, an alloy of copper and tin, replaced stone. After a time men found a way to extract iron from its ores, and the Iron Age began. As nothing has yet been discovered, or invented, to take the place of iron in the arts, the Iron Age has continued until the present day. The process of separating, or extracting iron from its ores; of smelting and refining it; and of making it into its most useful form, steel, is called the metallurgy of iron. From small beginnings, this art has gradually increased to its present importance.

ORES.

Iron is never found pure; it is always compounded with other elements or minerals. These compounds, called ores of iron, occur in enormous quantities, and are widely distributed in the earth. The value of an ore depends upon its richness, its locality, the ease with which it can be smelted, and its freedom from phosphorus and sulphur. The principal ores are:

Magnetite, magnetic iron ore (Fe_3O_4). It is black, heavy and crystalline. The finest quality is found in Sweden, and sometimes contains as high as 72 per cent metallic iron. This ore usually contains from 40 per cent to 60 per cent metallic iron. A high temperature is required to reduce it.

Hematite, oxide of iron (Fe_2O_3). A red ore containing about 70 per cent of iron when pure; it is sometimes called "Hard Ore." About 82 per cent of all the ore now mined in the United States is red hematite.

Limonite, or brown hematite ($2Fe_2O_3\ 3H_2O$). Contains water which can be expelled by heat, leaving the ore of a reddish

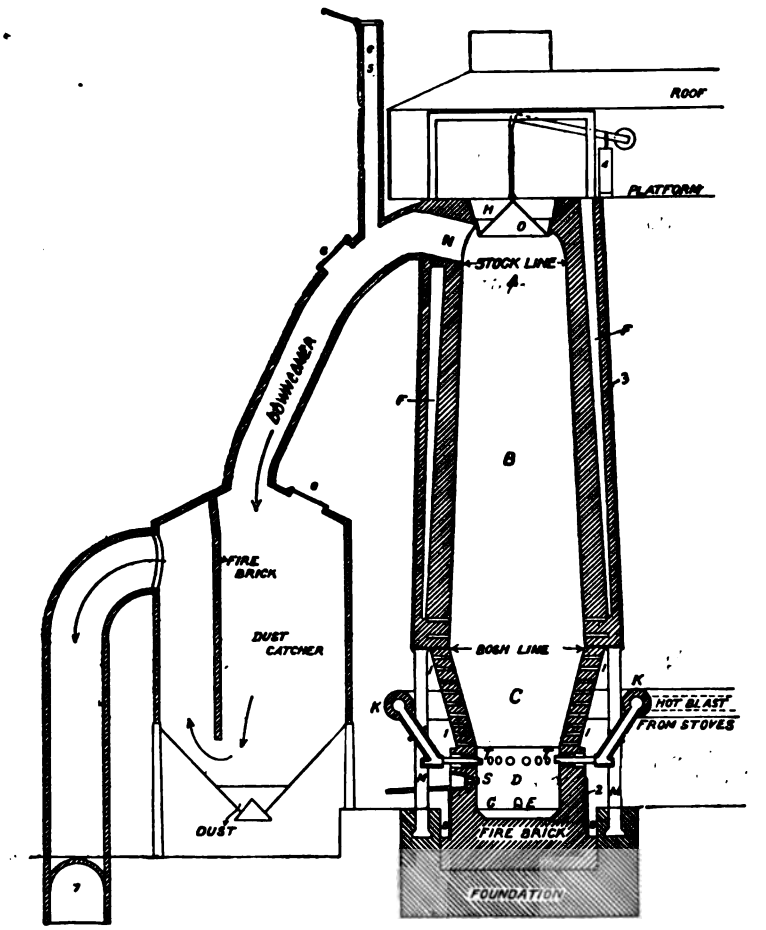


Fig. 1.

1. BRONZE COOLING PLATES.
2. CRUCIBLE JACKET.
3. SHELL.
4. BELL CYLINDER.
5. BLEEDER.
6. EXPLOSION DOORS.
7. FLUE LEADING TO STOVES AND BOILERS.
8. DITCH FOR WATER.

HEIGHT,	90 FEET.
DIAMETER AT BOSH LINE,	20 FEET.
DIAMETER AT CRUCIBLE,	14 FEET.
DIAMETER AT STOCK LINE,	15 FEET.
HEIGHT OF TUYERE CENTER,	8 FEET.
CAPACITY,	400 TONS PER DAY.

color. When pure this ore contains about 60 per cent of iron, and from 8 per cent to 20 per cent of water.

Siderite, or carbonate ($FeCO_3$) or ($FeOCO_2$). This is an important ore in Europe, although containing only about 48 per cent iron. It requires careful preliminary roasting before smelting.

Iron ores are never found pure; they contain varying quantities of silica, alumina, calcium, manganese, sulphur and phosphorus.

MINERALS.

The principal minerals used in iron smelting are:

Iron Pyrites or fool's gold (FeS_2). It occurs in cubic crystals and bright shining scales. This mineral is used as a source of sulphur in the manufacture of sulphuric acid. In some cases it is smelted for iron after its sulphur has been used.

Franklinite, or oxides of iron, manganese and zinc (FeO MnO ZnO) ($Fe_2O_3Mn_2O_3$). It contains about 46 per cent of iron. It is used in the manufacture of zinc white and spiegeleisen. "Spiegel," is a coarsely crystalline variety of cast iron, with large crystal planes having bright reflections. It usually contains about five per cent of combined carbon and 10 per cent to 20 per cent of manganese.

Limestone, *Chalk* or *Oyster Shells*, — carbonate of calcium ($CaCO_3$). Used as a flux.

Dolomite, carbonate of calcium and magnesium [(Ca Mg) CO_3], sometimes substituted for limestone.

PREPARATION OF ORES.

Usually the ore is broken into small pieces and then reduced to metallic iron in the blast furnace. Sometimes it is broken into small pieces, piled up, and exposed to the air and rain. By this means dirt, sand and soft rock are washed out. In this country iron ore is seldom roasted, but when necessary it is roasted in kilns, thus driving out the sulphur.

THE BLAST FURNACE.

The blast furnace is located in a place where materials may be economically assembled, product cheaply transported to market, and a good water supply is available.

The blast furnace is a circular brick or stone structure, lined with fire brick and encased in sheet iron. The general arrangement is shown in Fig. 1. The throat at A is about 15 feet in diameter; the main portion B, called the shaft, is nearly cylindrical and about 60 feet high and 20 feet in diameter. The lower portion C, which is shaped like an inverted frustum of a cone, is called the boshes and is about 20 feet high and 14 feet in diameter in the smallest part. Below the boshes a cylindrical portion D, called the hearth, extends about 10 feet and is lined with fire brick. This total height is about 90 feet, but some are over 100 feet high. The tuyeres T, 6 to 16 in number, are pipes through which hot blasts of air are blown and are built into the brickwork about 6 feet above the bottom of the hearth. The tuyeres are made as simple as possible and constructed so that they may be easily taken out and replaced. The bustle pipe K, supplies air to the tuyeres. The part of the hearth G, below the tuyeres is called the crucible, which being subjected to intense heat, is often cooled by water flowing through a series of open gutters around it. The boshes are kept cool by water circulating through a series of cooling rings, cast in bronze blocks and set in the brick or masonry walls.

There are two openings in the crucible wall; the upper, called the cinder notch for the removal of slag or "cinder," and the lower for the molten cast iron. The upper or "slag eye" S, is stopped up by an iron plug on a long handle; but the lower or "tap hole" E must be plugged with clay. Balls of clay are rammed in and soon baked as hard as stone by the heat. For large furnaces a "gun" is used to force the clay balls into the hole. This clay is two or three feet in thickness and when the iron is ready to flow out it is drilled. The work of drilling through this clay is considerable, and in modern furnaces is done by a steam tapping hole drill.

Just above the throat is the bell O and hopper H (Fig. 1). The materials are placed in the hopper and dumped into the throat of the furnace, by lowering the bell. The bell is raised and lowered by levers and counter-weights, operated by steam or compressed air.

The gases leave the top of the furnace just below the bell at

N; they pass through a dust catcher and then go to the stoves and boilers to be used as fuel. The stoves are used to heat the air for the tuyeres, and the boilers furnish steam for the blowing engines and hoisting engines.

The columns M support the weight of the furnace. The whole rests on the masonry foundation. The space F, called the expansion space, allows for the expansion of the inner wall; it is sometimes packed with granulated slag.

MATERIALS.

The materials used in the blast furnace are:

Ores, already briefly described.

Fluxes. Flux is the substance added to combine with the earthy impurities and make a fusible slag which floats on the molten iron. The impurities which would soon clog up the furnace, are thus removed. Limestone and Dolomite are the usual fluxes. Oyster shells are used in Maryland on account of cheapness.

Fuels. The fuels used are coke, which is made in beehive ovens from soft coal; charcoal, which is wood charred in heaps or kilns; anthracite coal, and very rarely bituminous coal.

The fuel depends largely upon the locality. Charcoal is a good blast furnace fuel on account of its porosity, slight ash, and freedom from sulphur. Coke is the best fuel because it is strong enough to resist being crushed by the great weight of materials and because it burns rapidly thus giving a large output. Anthracite coal breaks up very fine and burns to CO slowly. A good mixture is $\frac{1}{4}$ coke and $\frac{3}{4}$ anthracite coal. Bituminous coal is rarely used as it cakes and absorbs heat.

OPERATION OR RUNNING.

Blowing in. To start the blast furnace it is first thoroughly dried and then filled with cord wood to about half-way up the boshes. Upon this is placed a blank charge of coke, and then successive layers of fuel, flux and ore, with gradually increasing amounts of ore, until the regular charge is reached. The wood is then lighted and the hot blast of air turned on. At first this blast is under slight pressure. When coke is used the iron begins to flow in about 15 to 20 hours after lighting.

The ore, fuel and flux are brought to the scales in barrows called buggies. They are then weighed and wheeled to the elevator, and a certain number of barrows of each dumped into the hopper. In many large furnaces self-dumping cars are run to the top on an inclined railway, and the charging is entirely automatic. The fuel charge is usually dropped in by itself, followed by the ore and flux. The level of stock in the furnace is kept constant by regulating the charges. The temperature of the blast is kept as nearly constant as possible, being regulated by the admission of cold air. Cold water is kept running through the cooling rings around the bosh walls. Slag is either drawn off at intervals or continuously, and the molten iron which collects in the crucible, is drawn off every four to six hours by drilling the tap hole. It runs into channels formed in sand; the main channel is called the sow, and the smaller ones branching from it, the pigs. When solid the pigs are broken apart and stacked ready for transportation. The latest development in pig casting is an apparatus consisting of an endless iron mould which revolves and receives the charge and discharges the cooled pigs on the cars.

The furnace is run continuously day and night until it is necessary to shut down for repairs. Sometimes furnaces are run continuously for three to five years.

A good-sized blast furnace using coke as a fuel, will produce 300 tons of pig iron every twenty-four hours, and some of the largest can turn out 600 tons.

BANKING THE FURNACE.

It is sometimes necessary to shut down the furnace, because of a falling market, a flood, or a strike. If it is to be banked at a moment's notice, the first thing to do is to tap out the metal, shut off the blast and the water jackets; then close the furnace so that there will be no draft through the shaft. The tuyeres are blanked by ramming in clay balls. In this case the blast should be resumed in two or three weeks. If there is time to plan the shutting down, a large charge of fuel is dumped in and successive charges containing an increasing proportion of ore. The blast is shut off when the fuel reaches the tuyeres; the bell sealed and the cooling water decreased. The blast need not be resumed in this case for four or five months.

To blow out for repairs, stop the ore charges, and continue to charge fuel with a small amount of flux until the flow of metal ceases.

THE CHEMISTRY OF THE FURNACE.

In the blast furnace the oxides of iron give up their oxygen and become metallic iron. The most important substance for effecting this change is carbon monoxide CO. As we learned in Chemistry, CO gas has an affinity for oxygen, tending to form CO_2.

At the tuyeres the carbon burns to CO. Near the top of the furnace, at a temperature of 400° to 600° F, this CO reduces the iron ore (Fe_2O_3) to metallic iron, thus

$$Fe_2O_3 + 3CO = 2Fe + 3CO_2.$$

The iron is not melted here, but is in a pasty condition. The charge gradually descends, getting hotter and hotter. At the boshes it is at a bright red heat, and in the lower part the iron begins to melt, and the lime, silica and other earthy materials fuse and form slag. At this point part of the silicon, manganese, sulphur and phosphorus are reduced, and together with a little carbon, combine with the iron. In the crucible all is melted and the temperature is above 2200° F.

SLAG.

The earthy materials, silica, alumina, and sulphur of the ore and fuel, combine with the flux, and form the slag. A large part of the sulphur is then eliminated from the ore; but none of the phosphorus. The quality of the iron depends largely on the composition of the slag. If a high lime slag is used in order to reduce the sulphur and silicon in the pig iron, there is danger that the slag may not run well, in which case more alumina is used. A good slag has approximately the following constituents: 52 per cent $CaO + MgO$, 16 per cent Al_2O_3 and 32 per cent SiO_2.

STOVES.

In the first blast furnaces cold air was used for the blast. Stoves were introduced to effect a saving of fuel and to increase the out-put. The waste gases from the blast furnace contain about 25 per cent of carbon monoxide, CO, and 1 per cent of

hydrogen, H. These gases are burned with air in brick stoves and the fire brick flues are heated to redness. Then the cold air blast is run through and is heated to above 1000°F.

Four stoves are generally used in a set, three being heated while the fourth is giving out heat to the blast. The fuel consumption with a hot blast is about one-half that with a cold blast.

CAST IRON.

The iron produced by a blast furnace, known as cast iron or pig iron, is impure. It contains carbon, phosphorus, sulphur, silicon, manganese, and traces of other elements.

Cast iron is brittle, fusible and cannot be welded. It melts at a temperature of 2100°F. to 2300°F. Gray iron is more fluid when melted, and not as brittle as white iron.

Cast iron is suitable for castings because it expands at the moment of solidifying; this expansion is due to the change in the position of the crystals and results in a sharp impression of the mould. The casting is smaller than its pattern because the shrinkage in cooling from a red hot solid is greater than the expansion at the moment of solidification. If iron moulds are used, the surface of the casting becomes chilled, which causes a harder surface.

The Tensile Strength of cast iron is 13,000 — 29,000 pounds per square inch; Compressive Strength 82,000 — 145,000 pounds per square inch; Modulus of Elasticity 14,000,000 to 22,000,000.

Pig Iron is sometimes graded according to its fracture. This method is satisfactory if the irons are made from uniform ores and mixture of fuels; but is unreliable if the irons are produced in different sections of the country, or from different ores. Grading by chemical analysis is better. There are five standard grades according to hardness.

No. 1. Gray. Fracture rough. It is dark, open grain and the softest grade. Used exclusively in foundry work. Tensile Strength low. Elastic Limit low. Turns soft and tough.

No. 2. Gray. Mixed grain. Harder than No. 1. Fracture less rough, with higher Tensile Strength and Elastic Limit than No. 1. Used in foundry. Turns harder, less tough and more brittle than No. 1.

No. 3. Gray. Close grain. Used in foundry and rolling mill. Turns harder and less tough than No. 2.

No. 4. Mottled. Dotted with small black dots of graphite. Little

grain. Used in rolling mill. Lower Tensile Strength and Elastic Limit than No. 3.

No. 5. White, no grain, smooth fracture. Used in the Bessemer process and in the rolling mill. Tensile Strength and Elastic Limit lower than No. 4. Too hard to turn and very brittle.

The following table gives average analyses of the various grades of cast iron, the amounts being given as per cents:

Grade Number.	Iron.	Graphitic Carbon.	Combined Carbon.	Silicon.	Phosphorus.	Sulphur.	Manganese.
1	92.37	3.52	.13	2.44	1.25	.02	.28
2	92.31	2.99	.37	2.52	1.08	.02	.72
3	94.66	2.50	1.52	.72	.26	Trace	.34
4	94.48	2.02	1.98	.56	.19	.08	.67
5	94.68	——	3.83	.41	.04	.02	.98

INFLUENCE OF CARBON, SILICON, PHOSPHORUS, SULPHUR AND MANGANESE.

Carbon. The state of the carbon in the pig iron is a most important factor in the quality. If the carbon is combined with the iron in the form of an alloy, a hard, brittle, white iron is produced. If it is present mainly as graphite distributed as small crystals throughout the entire mass, the iron is soft and gray in color, but not as strong as white iron. Gray iron expands more on solidifying and contracts less in cooling than white iron.

Silicon. The amount of silicon and the rate of cooling determine the proportion of graphitic to combined carbon in the casting. Increasing the silicon in cast iron increases the proportion of graphitic carbon, thus making the iron softer. A large quantity of silicon renders the iron stiff and weak.

Phosphorus. Phosphorus in general weakens cast iron, but it is not harmful if less than 1 per cent is present. In some cases phosphorus is beneficial, as it decreases shrinkage and increases fluidity. For small, thin castings, iron may contain a little over 1 per cent phosphorus.

Sulphur. Sulphur makes castings hard and unsound. It

also prevents the iron from flowing well. The amount of sulphur should not be over .5 per cent for sharp castings.

Manganese. Manganese in cast iron increases hardness and shrinkage and makes it more brittle. Manganese makes the iron capable of holding more carbon. Sometimes the amount of carbon is as high as 5 per cent, as in Spiegel.

Manganese with some chill is used in the foundry to produce hardness of surface. The magnetism of iron is decreased by manganese; if 25 per cent is present all magnetism is lost.

CASTINGS.

In order to get a good casting, an iron having the following requisites should be used:

Shows gray fracture.
Is easily worked by tools.
Fills the mould to the thinnest parts.
Chills with a smooth surface.
Free from blow-holes.
Has moderate strength.
Little shrinkage.

An iron with the following constituents fills these conditions:

Carbon,	**3½ per cent.**
Silicon,	**1½ per cent to 2 per cent.**
Phosphorus,	**not over .7 per cent.**
Sulphur,	**only a trace.**
Manganese,	**.35 per cent to .70 per cent.**

For large castings lower the silicon. For increase in strength lower the carbon, silicon and avoid phosphorus. For resistance to chemical action make the manganese as high as brittleness will allow.

Silver-gray and ferro-silicon irons are used to increase silicon. Spiegel and ferro-manganese are used to increase manganese. Both wrought iron and steel scrap are used to reduce carbon.

MALLEABLE CAST IRON.

Malleable cast iron is a crude form of wrought iron obtained by decarbonization. The castings are made in the ordinary way from low silicon iron with little phosphorus and sulphur; they are embedded in oxide of iron or peroxide of manganese and heated to a red heat until most of the carbon is removed from the

surface. The time necessary for this operation is three to fourteen days, depending upon the size of the casting.

An analysis for good malleable iron is:

Si	.75 — 1.00 per cent.	P	.20 per cent.
S	below .05 per cent.	Mn	.40 to .75 per cent.

This wil be a No. 3 iron.

In making malleable castings, sharp angles and abrupt changes from heavy to light sections should be avoided. Several thin ribs in place of one thick rib should be used. As much surface as possible should be exposed, as the strength lies in the skin.

WROUGHT IRON.

Removing most of the carbon, silicon, phosphorus and manganese from pig iron makes it tough, malleable, harder to melt and capable of being welded. This iron is known as wrought iron, and is obtained by a process called puddling. The operation of making wrought iron from the ore is called a Direct Process. On account of its simplicity it was the first used.

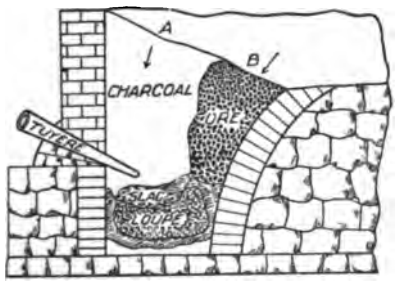


Fig. 2.

The Direct Processes are carried on at a low temperature; the production is small and variable, and about 20 per cent of the iron in the ore is lost. One of the oldest methods of making wrought iron directly from the ore is the Catalan Process. Ore of egg size is charged at B, Fig. 2, and charcoal at A. As the smelting progresses, charcoal and moist fine ore are charged at A. As the ore becomes reduced it works towards the tuyere; when it is all reduced it is taken out in a large lump called the "loupe" and worked under a hammer.

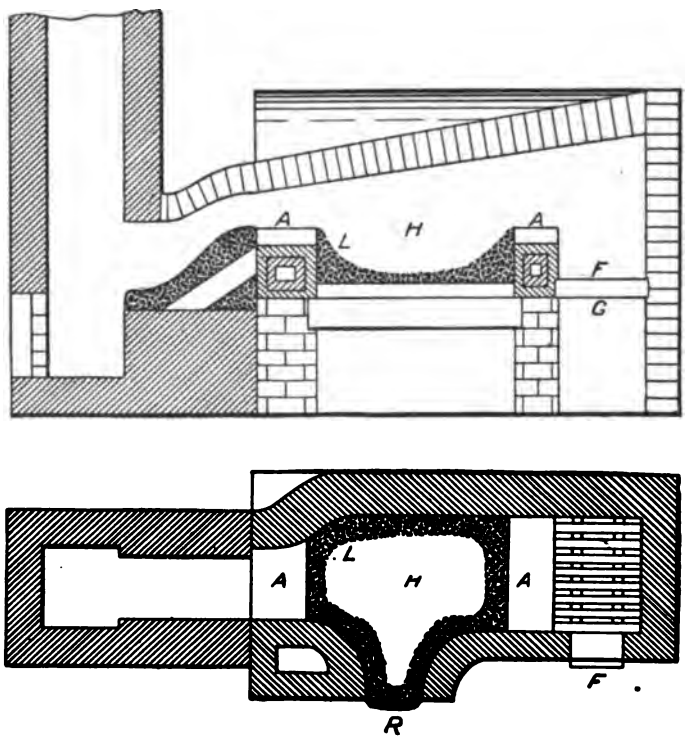
There are other processes, but they are unimportant and most all have been abandoned.

THE PUDDLING PROCESS.

The refining of pig iron by puddling converts it into wrought

iron. This process is carried on in a reverberatory furnace. Fig. 3 shows sectional view of the plan and elevation.

The furnace has a low-arched roof and oval hearth H. The flame from the fire passes over the charge of iron, which is melted by the intense heat. The pig iron used in this process is gray and unrefined and has more silicon than white iron. The fettling or lining L of the hearth is made of good magnetite or hematite. The fettling is repaired after every heat.



A. — BRIDGES. F. — FIRE-DOOR. Fig. 3. G. — GRATE. R. — RABBING-DOOR.

Carbon, silicon, manganese, phosphorus and sulphur unite with oxygen from the hot blast and the iron ore lining, thus reducing the molten metal to wrought iron. In order that the whole of the metal may come in contact with the fettling it is stirred constantly by rods called "rabbles." It takes about thirty minutes to melt down, and then carbon begins to be oxidized to

CO gas, which makes a violent boiling for about 15 minutes. The silicon, manganese, etc., oxidize and form a slag. When all the carbon is boiled out, bright points appear and the iron becomes pasty. The iron is gathered into balls and then worked under the hammer and rolls to expel the slag. It is afterward reheated and rolled between grooved rollers, which causes the particles to become close together. If the bar is rolled once it is called muck bar; if cut up, heated and rolled again, merchant bar; the best bar iron is rolled a third time.

The Puddling Process and the manufacture of wrought iron is gradually giving way to mild steels; but because of the small amount of slag it contains between the fibres, which acts as a flux, wrought iron welds much easier than steel and is preferred by blacksmiths.

The Puddling Process is expensive on account of the large amount of fuel used in the production of metal. About one ton of fuel is necessary to produce one ton of muck bar. For this reason and on account of the expense of the mechanical work of puddling, many efforts have been made to produce a cheaper and more simple process.

Boilers have been mounted over the furnace to utilize the waste gases as fuel, but on account of the fluctuating heat of the furnaces they have not been entirely successful. Water-tube boilers mounted in this way have been the most satisfactory.

There are several contrivances to save fuel and labor, but as the mechanism is likely to get out of order, they are not always reliable. For saving of labor, the Dank's Puddling Furnace, Fig. 4, is the most efficient and satisfactory of the mechanical puddlers. It is shaped like a short barrel, lying on its side. It is supported by friction rollers, two at each end, and driven by a large gear G around its middle. In this furnace the revolving of the hearth takes the place of puddling or stirring by hand.

Iron ore worked in layers at low heat forms the fettling. It is fed with molten iron from a furnace by means of a ladle. In some places this furnace is used for ordinary puddling, and in others for making wrought iron for the Open-hearth and Siemens Processes for making steel.

Wrought iron contains from .5 per cent carbon to only a

trace; as carbon decreases, malleability increases, and the melting point rises. The melting point of good wrought iron is about 3000°F.

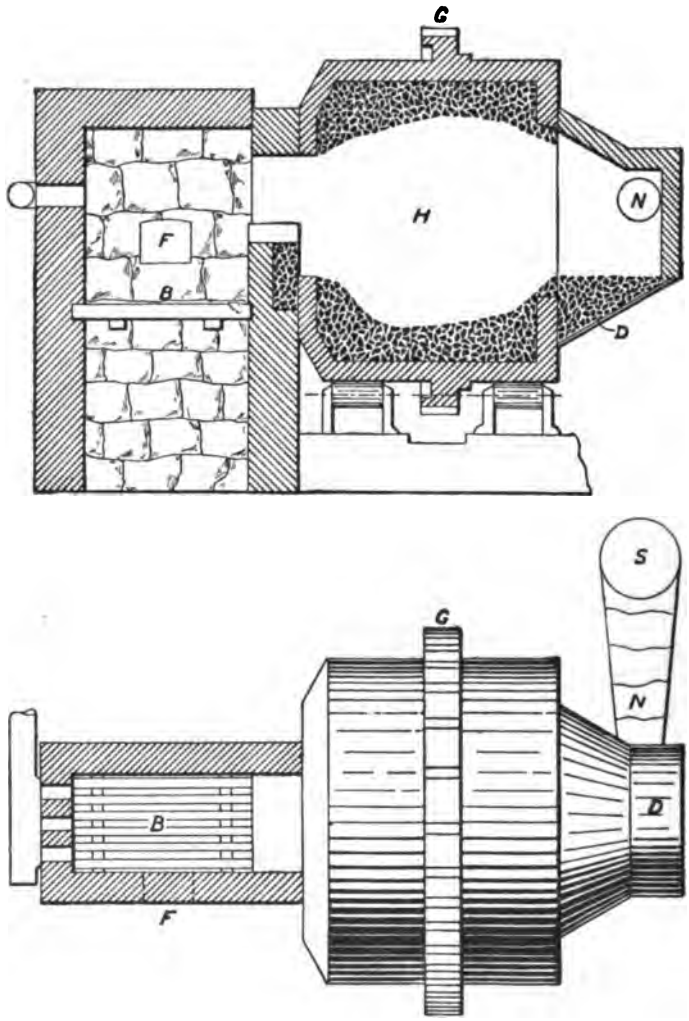


Fig. 4.

B — GRATE.
F — FIRE-DOOR.
H — HEARTH.
D — MOVABLE FLUE-PIECE.
N — FLUE TO STACK.
S — STACK.

Wrought iron contains about 2 per cent of slag distributed among the fibres. It is always present because the iron is finished

in a pasty condition and the slag is never completely removed by the subsequent squeezing and rolling.

The fracture of wrought iron is coarsely fibrous, sometimes showing a few bright granular spots. The best iron is granular when broken suddenly.

The reduction of area of bars by rolling influences the strength and elastic limit. In general, the greater the reduction the higher the strength and elastic limit. Underheated bars have an unduly high tenacity and elastic limit.

The absolute strength of wrought iron is not materially altered by cold. The extensibility, or ductility, is not less in severe cold than at ordinary temperature. The modulus of elasticity rises as the temperature falls.

WELDING.

The process of welding consists of heating two pieces of iron to a high temperature, laying them together and hammering. Borax is sometimes sprinkled on the surfaces to be united, in order to keep them bright. This is accomplished by the union of borax with the oxide forming a fusible borate. In order that the form of the piece after welding may not be spoiled by hammering, the two ends to be joined are upset and scarfed. The upsetting makes the ends larger, so that they may be hammered without making the joint too small, and the scarfing roughens the ends, making the pieces join more easily.

STEEL.

CEMENTATION PROCESS.

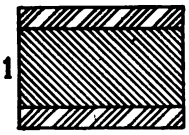
Cement or blister steel is made from wrought iron by this simple process. The purest, soft wrought iron is heated to redness while completely covered with charcoal. The temperature is kept constant for over a week. The iron takes up some of the carbon from the charcoal and is converted into steel. It is called blister steel on account of its appearance, the surface being covered with small scales or blisters. These bars of blister steel are cut, heated and rolled together, forming shear steel. If the process is repeated, the product is called double shear steel.

Blister steel that has been cut up, melted in a black-lead pot and cast in an ingot, is called cast or crucible steel.

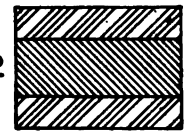
The metal used in Sheffield, England, is wrought iron made from Swedish pig iron. Hammered wrought iron bars are laid in firestone pots in layers, surrounded with charcoal. At one end is placed a test bar, so arranged that it may be drawn out, examined, and returned. The temperature is gradually increased for 7 days to about 1150° F., and then the furnace is kept at this temperature for 7 or 8 days more. It takes 7 days for it to cool down.

When the bars are taken from the charcoal, the outside layers are converted into steel, leaving the center wrought iron. The use for which this steel is intended determines the amount of conversion; the various kinds are classified as follows:

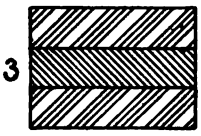
(1) Spring heat, .5 per cent C.
Large iron center.



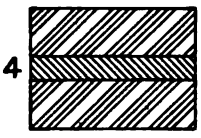
(2) Country heat, .63 per cent C.
Smaller iron center.



(3) Single shear heat, .75 per cent C.
Equal iron and steel.

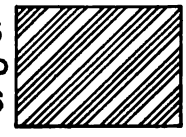


(4) Double shear heat, 1 per cent C.
Mostly steel.



(5) Steel through heat, 1.25 per cent C.
All steel.

(6) Melting heat, 1.5 per cent C.
All steel.



The reaction which takes place is

$$4Fe + 2CO = Fe_4C + CO_2.$$

CRUCIBLE PROCESS.

The materials are bar iron with charcoal, puddled bar or blister steel and charcoal. The crucibles are made of clay or graphite, with a capacity of 50 to 85 pounds. The charge is put into the crucible, and after melting is allowed to stand for a time, called the killing period, and then poured into moulds.

In American practice, graphite crucibles are used, which are made from a mixture of fire-clay and sand, and about 50 per cent graphite. This mixture is ground, allowed to stand for a few days, and is then moulded by being pressed into a wooden mould. When dry, it is baked in a kiln. These crucibles can be used about five times, if the successive charges are gradually diminished in amount.

The crucible is charged cold. The pieces of iron are surrounded with charcoal, with a little manganese, and sometimes a little salt or ferrocyanide of potassium mixed with it. This crucible, after being covered, is placed standing on the coal in a hot furnace. After three hours, during which the contents are melted, the cover is lifted, and the melter examines the charge to determine the length of the "killing" period. During this period, which is about 45 minutes, the metal is becoming tranquil and is taking silicon from the sand in the walls of the crucible. The silicon prevents blow-holes. At the right time and temperature the crucible is lifted out and the slag skimmed off. The metal is now ready for casting, or "teeming." This is done by pouring the metal into split moulds.

The ingots are graded and hammered into bars for different uses. Crucible steel furnishes the finest grades for cutlery and machine tools; it is superior to Bessemer and Open-hearth steel, because pure materials are used and the process is carried on in a closed vessel, thus protecting the metal from sulphur gases from the fuel.

It has low phosphorus, low sulphur, no iron oxide, less gases, high carbon and high silicon.

Crucible steels are graded as follows:

Razor. 1¼ per cent C. Easily burned, very hard temper, welded with difficulty.

Saw-file. 1¼ per cent C. Not easily burned, hard temper.

Tool. 1¼ per cent C. Not easily burned, hard temper, welded with difficulty.

Spindle. 1½ per cent C. Not easily burned, hard temper, welded with difficulty.

Chisel. 1 per cent C. Not easily burned, fair temper.

Set. ⅞ per cent C. Difficult to burn, little temper, easy to weld.

Die. ¾ per cent C. Difficult to burn, little temper, easy to weld.

THE BESSEMER PROCESS.

Bessemer, by his experiments, found that the temperature of molten metal was raised by blowing a current of air through it.

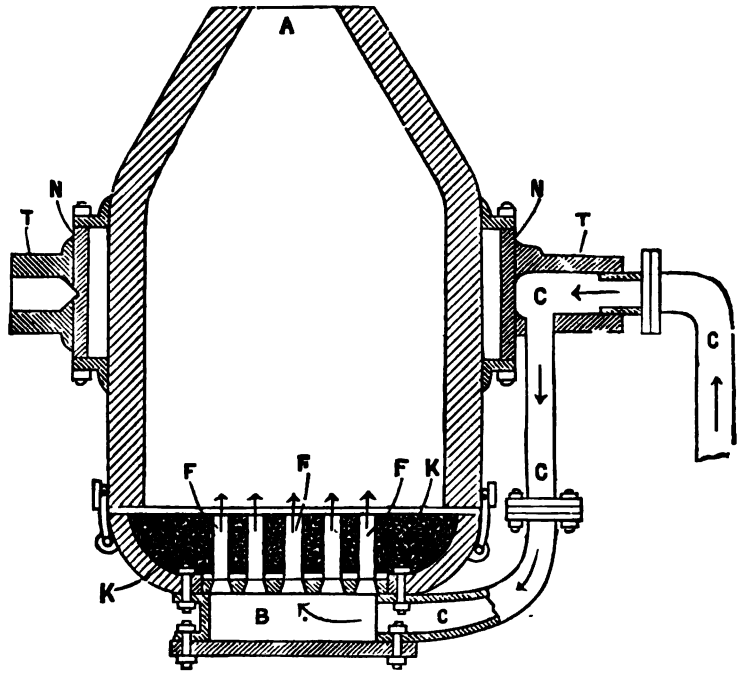
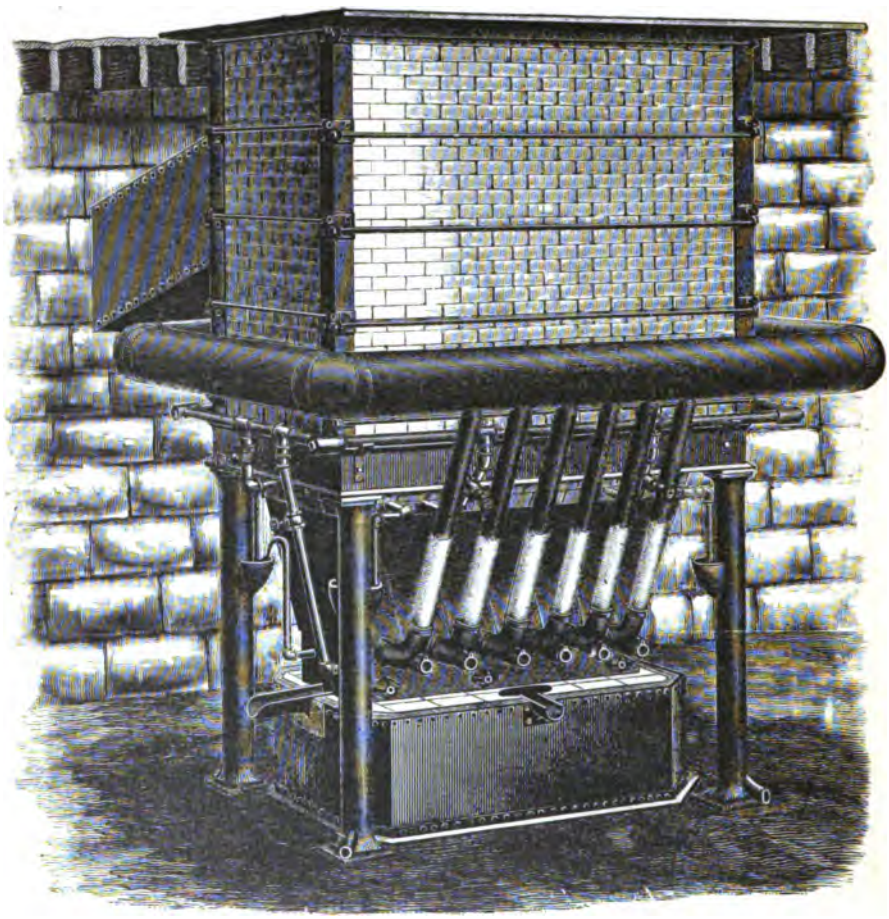


Fig. 5.

He tried to make wrought iron from pig iron, but found that the metal taken from the converter at that point was worthless; by restoring carbon by means of an alloy the product was better than wrought iron.

By this process steel is made from pig iron by burning out the foreign substances and replacing the necessary amounts of carbon, and manganese. These foreign substances — silicon, car-



STEEL WATER-JACKETED BLAST FURNACE FOR LEAD ORES
RECTANGULAR TYPE
Allis-Chalmers Company

bon and manganese — are burned out by blowing a blast of cold air through the molten pig. The desired amounts of carbon and manganese are replaced by mixing the proper proportion of spiegel with the molten pig.

The process is carried on, not in a furnace but in a vessel called a converter, in which molten pig is "converted" into steel.

There are several forms of converters. Fig. 5 shows a concentric converter. It is round, with a detachable flat bottom. The outer casing is of sheet iron. It is filled and emptied at the nose A. The current of cold air enters through the pipe C, and passes through the trunnion T. It enters the converter from the wind-box B, passing through the tuyeres F. The tuyeres are of fire brick 24 to 28 inches long, and have 19 holes $\frac{5}{16}$ inch in diameter, or 7 holes $\frac{8}{8}$ inch in diameter. The trunnion rings N are fastened to the converter, which turns on the trunnions T. The bottom is coupled on with clamps.

The pig iron is not melted in the converter, but poured into it in a molten state.

There are two processes of working.

(1.) The Acid Bessemer.

(2.) The Basic Bessemer, or Thomas-Gilchrist.

The difference is in the lining of the converter. If this lining is acid (siliceous) no phosphorus or sulphur is burned out of the pig. Only irons with small amounts of these elements can be used in this process. If the lining is of lime or magnesia all the phosphorus and almost all of the sulphur can be burned out. Only a high phosphorus pig can be used in the basic process, as the heat needed to keep the steel liquid, during casting, is obtained from the phosphorus.

The Basic Process is used in Germany with good results.

In both processes the carbon, silicon, manganese, etc., are oxidized, leaving the molten iron in a condition similar to that of wrought iron. The carbon passes away as CO, and the oxides of silicon and manganese with a little iron oxide form a slag. Molten spiegel is added to give it the necessary carbon, and a little manganese to make it malleable. The molten pig is obtained in two ways; by melting the pig in cupolas, called the Cupola Process; and by taking the iron from the blast furnace, called the Direct Process.

THE CUPOLA PROCESS.

Pig iron, from piles which have been sampled and analyzed, is loaded into trucks and wheeled to the cupolas. The composition of this mixture is about as follows:

Silicon	1.75 per cent.
Manganese	.75 per cent.
Sulphur less than	.05 per cent.
Phosphorus less than	.10 per cent.
Copper less than	.10 per cent.

This is weighed, hoisted to the cupola and dumped in. Spiegel is sampled, analyzed and melted down in smaller cupolas. The fires in the cupola are started with wood upon which is placed coke; the charges of pig iron being dumped on the coke. It takes about two hours to melt the first charge. As some silicon burns out in the cupola the percentage is reduced. When the iron goes into the converter there must be from 1 to 2 per cent silicon present, depending on the temperature of the iron.

THE DIRECT PROCESS.

In the ordinary blast furnace, different casts differ too much in silicon and sulphur to allow taking the metal as it flows from the furnaces into the ladle and then to the converter. Therefore, it is first poured into large reservoirs or mixers, in which the casts from the different furnaces are mixed. In Sweden, however, the product from a number of small charcoal furnaces is regular enough for the iron to be used directly. The iron is taken from the mixers as wanted and used as cupola iron. If the iron stands in the mixer a long time some sulphur is eliminated, but no carbon or silicon. To prevent the iron from chilling on top, a jet of oil is sprayed over it. As the temperature of direct iron is greater than that of cupola iron, less silicon is needed.

Blowing. The heated bottom is coupled on and the joint rammed tight from the outside. When the lining is made yellow-hot by means of a fire of wood and coal with a gentle blast, the iron from the cupola or the mixer is poured in and the blast turned on.

The converter is turned up to a vertical position, as shown

in Fig. 6, as it is filled when turned down on its side. The blast rushes up through the bath, and silicon begins to oxidize raising the temperature high enough for the carbon to burn. Carbon burns to CO. The blower judges whether there will be enough heat to keep the steel liquid during the casting, by the appearance of the flame which comes out of the throat of the converter. If he thinks there will not be enough heat, the converter is turned half-way down and the CO burns to CO_2. Fig. 7 shows the converter turned down until the tuyeres are exposed.

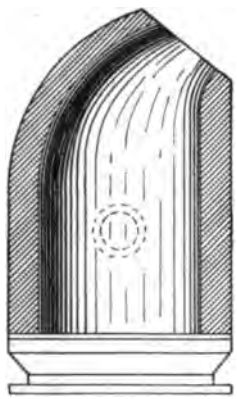


Fig. 6.

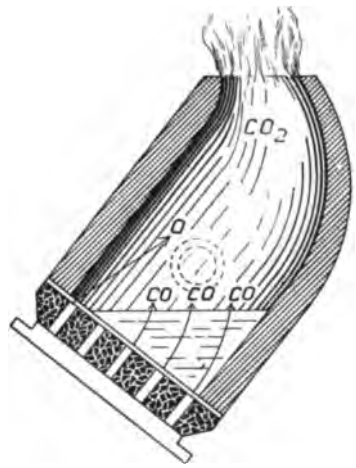


Fig. 7.

In case there is too much silicon for good working, or if the charge is too hot, cold steel scrap is dropped into the nose of the converter from a platform above. The scrap, being free from silicon, reduces the percentage of silicon in the converter. If the steel is made too hot it will not roll well. Sometimes a jet of steam is admitted to the blast pipe to cool down a charge. The carbon is reduced to about .05 per cent after about 12 minutes blowing under a pressure of 30 pounds per square inch. This is shown by a shorter flame. An instant later the flame becomes fringed with brown smoke which is Fe_2O_3. The converter is now ready for the spiegel. The spiegel contains about 20 per cent manganese and 4.5 per cent carbon. If hard steel is being made, spiegel is used, but if it is to be soft, which requires

some manganese and but little carbon, ferro-manganese is used instead of spiegel. This has 80 per cent manganese and 6.5 per cent carbon. The amount of molten spiegel added is about 10 per cent of the weight of the converter charge, and of ferro-manganese from 1 per cent to .8 per cent. The ferro-manganese is not remelted but shoveled red hot in pieces the size of an egg into the casting ladle. After the steel has been poured out into the ladle most of the slag remains in the converter. It is dumped into a car beneath by tipping the converter bottom up. This loss or waste is from 10 per cent to 12 per cent.

The charge varies from 5 tons in a small converter to 20 tons in a large one, and a new charge is blown every twenty minutes. The bottoms of the converters are examined and any bad tuyeres are plugged with plumbago mud and blanked. The life of one of these bottoms varies from 18 to 25 "blows." The conditions which injure the bottom are low blast, a great depth of metal above the tuyeres, too much Al_2O_3 and Fe_2O_3 in the ganister mixture, and dampness of the repairing material. The bottoms are dried four days in a drying oven; several of these are always kept on hand drying, for if not absolutely dry, they are useless.

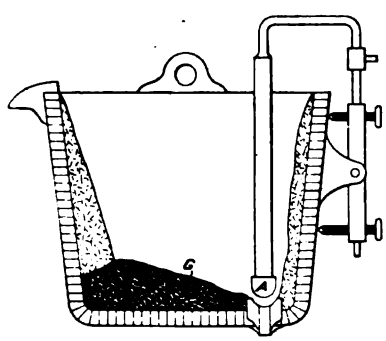


Fig. 8.

"Acid" Converter Lining. Converters are lined with blocks of ganister with the joints faced with ganister mud. If pure ganister is used it is likely to give trouble on account of its expansion under heat. Too much Al_2O_3 causes the lining to melt out rapidly. The bottom is lined with a mixture of ground ganister and fire clay. Ganister, a flinty sandstone, is composed of about 98 per cent of SiO_2 with about 1 per cent or 2 per cent of $Fe_2O_3 + Al_2O_3$. The fire clay has about 86 per cent of SiO_2, 10 per cent Al_2O_3 and 4 per cent of alkalies. If the manganese in the pig iron is less than $1\frac{1}{2}$ per cent the linings last for months. A high lime slag in the pig will rapidly flux

THE PARROT CONVERTER
Allis-Chalmers Company

the SiO_2 of the lining. The nose section is lined with brick or stone and lasts but a short time.

The Casting Ladle. The general shape and arrangement of the casting ladle is shown in Fig. 8. The shell is made of iron plate and is lined with a layer of brick and upon this is pounded moist loam. The bottom G is made of rammed ganister material. The pouring hole is fitted with a cylindrical brick nozzle, with a hole 2 to 4 inches in diameter. The stopper A sets upon a bowl shaped seat. The stopper and stopper slide are shown in the figure. The end of this stopper, which fits the seat, is made of plumbago. The lining of the casting ladle lasts about 40 blows. A new nozzle and stopper is put in about every fourth blow.

Moulds. The moulds must be hard enough to withstand the strain caused by expansion and contraction when heated or cooled, yet not brittle. These moulds, if made of iron, have a composition as follows:

Silicon	1.7 per cent
Phosphorus	.1 per cent
Manganese	.75 per cent

Moulds are made of gray iron as white iron is too brittle. These moulds last about 90 operations.

INGOTS.

Method of Pouring. Great care is necessary in the pouring of ingots. They should be poured in such a manner as to prevent spattering, oxidation of the surface and injury to the mould. There are three principal methods: Top pouring, the most natural, bottom pouring, and a combination of top and bottom pouring. The greatest objection to ordinary top pouring is that of spattering and oxidation of the surface. These are partly overcome by the admission of the molten metal through a pipe which reaches nearly to the bottom of the mould. By mechanical means, this pipe slowly recedes, so that the distance between its end and the surface of the metal is nearly constant. If the mould is bottom poured, the metal at the bottom, being kept hot, has a tendency to thin the bottom and walls of the mould. If they become too thin they are likely to crack or burst. The slag has to

rise through the entire column of metal and if this becomes cooled particles of slag become entangled. Also, the slag has a tendency to solidify in the pipe by which the metal is introduced, thus causing poor ingots. The best results have been obtained from a combination of top and bottom pouring. During the first half of the time the metal is bottom poured and then finished by top pouring. In this case, the gases and slag have only a short distance to rise.

Shape of Ingots. Ingots are usually square with rounded corners slightly tapered to one end, so that they may be easily removed from the mould.

Gases and slag rise to the top of the ingot. Sometimes a "pipe" is formed in the center by the metal solidifying and shrinking away from the center. To prevent this the top is kept liquid longer by a covering of sand. It is advantageous to keep the cavity near the top, so that a large portion of the ingot will be sound. Another method is to cast ingots one on top of the other in a column, pouring one as soon as the preceding one has begun to solidify. This brings the cavity and imperfections in the last ingot. Another remedy is to cast the ingots longer than is necessary and cut off the top; but this is a waste of metal for the cut off portion has to be remelted and recast. Another way is to make the top rounding, in order to allow the impurities and gases to collect in the rounded part.

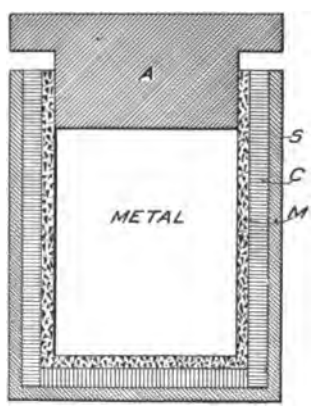


Fig. 9.

We learn from Chemistry that the solubility of gases in liquids increases with pressure; this principle is made use of in the casting of ingots. The mould is arranged as in the accompanying diagram, Fig. 9. The outside S is formed of steel in which is a thin layer C of perforated cast iron, the mould being lined with moulding sand M. The top plunger A is stationary. The mould is made to rise by powerful machinery. When the metal has begun to solidify the mould is raised until the pressure

becomes 10 to 20 tons per square inch; this pressure is kept on for about 20 minutes. The gases are not squeezed out by this process; the pressure tends to dissolve them. This process is used in making armour plate and gun tubes, but is too expensive for ordinary use.

Rail Making. Very soon after an ingot is poured it commences to solidify at the surface. A solid shell forms with a pasty or liquid interior. As the ingot cannot be rolled until it has become of uniform softness it is put in a "soaking pit." By means of currents of hot gases, the ingot soaks or equalizes, that is, it becomes uniform throughout. It soaks in these hot gases for about an hour. The ingot is taken from the soaking pit by an electric traveller, and is rolled down in the blooming mill to a "bloom" of about 7 inches by 7 inches in section, which, after the ragged edges have been cut off by hydraulic or steam shears, is finished, without re-heating, in a rail mill. Sometimes the bloom is allowed to partially cool and is then reheated before being finished. This process is expensive on account of the fuel and labor, but it reduces the number of defective rails. The whole ingot is rolled in the rail mill into one long rail, and this is cut into standard lengths by hot saws. After the rails cool they are straightened in steam presses and are then inspected and bolt holes drilled in the ends. Steel rails have the following composition:

Carbon,	.40 per cent to .6 per cent
Phosphorus,	.08 per cent to .1 per cent
Manganese,	.75 per cent to .9 per cent
Sulphur,	.05 per cent to .1 per cent
Silicon,	.05 per cent to .15 per cent
and sometimes Copper,	.01 per cent to .2 per cent

If the carbon is above .6 per cent the rail will be too brittle and will break under the drop test. In this test a heavy weight is allowed to fall through a specified distance on a piece of rail about 3 feet long, supported at the ends.

If the carbon is below .4 per cent the rail is too soft to stand the wear of the car wheels; if the phosphorous is above .1 per cent the steel will be "cold short" (brittle); if the manganese is much below .75 per cent the ingot will crack in rolling; if the

sulphur is above .1 per cent there will be short feathery cracks in the ingot when rolled, especially if rolled at a low red heat. Silicon up to .15 per cent improves the rolling qualities of the steel, but makes the steel brittle if the percentage of silicon is much higher.

The Bessemer process is also used in making soft steel. This steel is made into barbed wire, wire nails, hoop iron and sheets for tin plate and galvanized iron; it is also used for some structural steels and agricultural implements. This steel has about .1 per cent to .15 per cent carbon, and .4 per cent to .5 per cent manganese.

About 70 per cent of the steel made in the United States is Bessemer steel, and about 30 per cent of this is made into rails.

THE OPEN HEARTH PROCESS.

The Open Hearth Process for making steel is divided into three methods, according to the character of the material used. They are,

1, The Martin Process, in which pig iron and scrap are used.

2, The Siemens Process, or "pig and ore" in which pig iron and ore are used.

3, The Combination Process, using pig iron, scrap and iron ore.

The open hearth process was made possible by the invention by Siemens of the regenerative chambers, first successfully used by Martin, and is often called the Siemens and Martin process. The fuel is gas, which is burned on the hearth of a large reverberatory furnace. Both the gas and air are heated by the products of combustion in the regenerative chambers, as represented by Fig. 10. The heated gas and air enter the furnace on the left, burn on hearth H, and the products of combustion pass out and down through the chambers A and G on the right. These chambers are filled with fire brick set up with spaces between, called checker work, which becomes heated to a white heat. After a time the currents of gas and air are reversed and pass through the checker work just heated, becoming highly heated before they combine and burn, thus the heat is "regenerated."

The currents are reversed once every half-hour (to an hour)

MODERN ORE UNLOADING MACHINERY AT THE GREAT LAKES

(By courtesy of the *Engineering Magazine*, New York and London)

and a very intense heat is maintained so that the metal in the condition of wrought iron is kept in a molten state.

In this country the combination process is generally used. With this process the scrap and pig iron are first melted. As this iron contains too much carbon, iron ore is added to reduce the percentage. This process, like the Bessemer, has two main divisions, the Acid and the Basic open-hearth processes, having siliceous and lime-magnesia linings respectively, and like the Bessemer process, only low phosphorous iron can be used with the acid lining while high phosphorous stock is used with the lime lining. In the

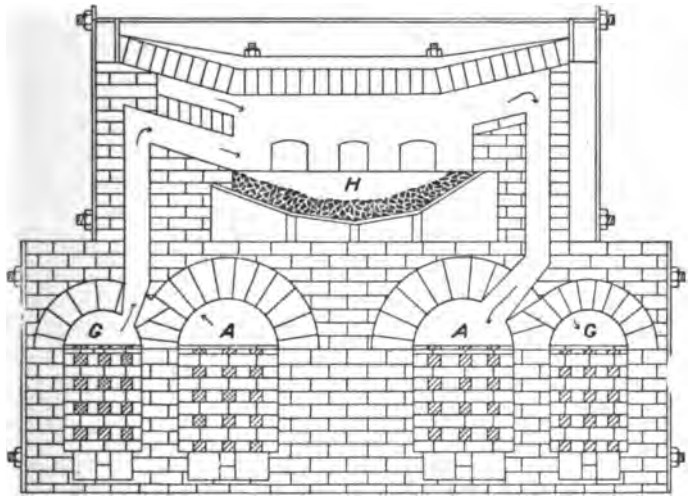


Fig. 10.

Bessemer process only medium and low carbon steels can be made, while in the open-hearth, steel of any grade of carbon can be made. This process also has the advantage of being more under control, and the product is more uniform, more reliable and contains less gas. Open-hearth steel costs about $2.00 a ton more than Bessemer.

Open-hearth steel is used for making spring steel (carbon .8 per cent to 1 per cent) for cars and wagons; structural steel for bridges and buildings; steel for agricultural implements and tools; cast steel and mild steel (low carbon) for boiler plates (carbon .15 per cent, and phosphorus .03 per cent).

The Bessemer process and open-hearth process can be advantageously carried on together, as the scrap and "crop ends" of the Bessemer are largely used in the open-hearth.

MANAGEMENT, OR RUNNING THE ACID PROCESS.

At the start the furnace is heated by a wood fire, and then the gas is turned on and lighted. When the temperature is sufficiently high to melt steel, the charge is put in. It consists of one-third pig iron, and the rest wrought iron and steel scrap. On account of the low melting point of pig iron, one-half of the pig iron is put in first on the bottom. If steel or wrought iron were charged first, it would be slow in melting. The scrap is then put on and covered by the rest of the pig, and currents of air and gas are reversed at intervals, each time coming up hotter. In four hours it is all melted, but the carbon is too high, and it is not yet ready for casting. To expel this carbon small amounts of iron ore are added. CO is produced, which boils off.

$$Fe_2O_3 + 3C = 3CO + 2Fe.$$

This boiling continues until the desired percentage of carbon is reached, which is determined by sampling. These samples are taken out at intervals, cooled and broken; the percentage of carbon being judged by the appearance of the fracture. As the boiling down occupies three or four hours, there is time for an approximate chemical analysis. Manganese and silicon have both been absorbed by the slag, therefore some manganese must be added before casting. This is done by adding to the casting-ladle red-hot spiegel, or ferro-manganese, the size of peas. If steel castings are being made, a little silicon must also be added, to prevent blow-holes. When the steel is ready chemically, it is usually hot enough to cast. The furnace is tapped by driving a bar through the tap-hole, and the molten metal flows out of it into the casting-ladle, which is similar to that of the Bessemer process. The casting is done in moulds, as in the Bessemer process. Bottom pouring is often employed, especially if the ingot is to be made into steel plate. The bottom of the mould has to be repaired after each operation.

MANAGEMENT OR RUNNING THE BASIC PROCESS.

The furnace used is very similar to that of the acid process, except for the lining, which is of dolomite or magnesite. Dolomite is hard-burned lime made from a magnesia limestone. Magnesite is made from $MgCO_3$, calcined several times at high heat. Layers of dolomite or magnesite, mixed with 10 per cent of boiled tar, is rammed in with hot rammers all over the bottom and sides, above the slag line. Upon this hearth, scrap and high phosphorous pig iron are melted down. To prevent fluxing of the lime lining, limestone is spread over the bottom before charging. After melting there is too much phosphorus and carbon in the charge. These elements are oxidized by the addition of the iron ore. The agitation and boiling of the phosphoric bath is caused by the escaping gas, CO, and the metal is thus brought in contact with the basic slag and the phosphorus removed. If all the phosphorus is not out at this point, pig iron is added to raise the percentage of the carbon, and the bath is again boiled down. The appearance of the fracture of the sample indicates the amount of phosphorus present. If there is a large amount, two cross-lines of bright crystals, called the "Phosphorus Cross," appear in the center. The casting is the same as in the Bessemer process. The wear of the basic lining is greater than that of the acid, especially if the silicon is high. Holes in the hearth are repaired after each heat.

The tap-hole is rammed with tar dolomite or magnesite.

In an ordinary open-hearth furnace only two heats can be made in a day. The charge varies from 10 tons in a small furnace to 50 tons in a large one.

Tilting furnaces are being used in modern plants, which lessen the time of charging and working, and "direct metal" from mixers is used in place of pig, which further reduces the time. Altogether, the open-hearth process is gaining in favor in this country. The basic process is more used than the acid, because high phosphorous pig is cheaper.

GAS PRODUCERS.

Gas is the fuel used in the open-hearth process. The Siemens Gas Producer is now little used, most gas being made by the

Wellman Gas Producer. Fig. 11 is the sectional view of this producer. A forced draft, usually a steam-jet injector, supplies steam and air to the furnace under slight pressure. The following reactions take place when air or steam unite with coal:

$$C + O_2 = CO_2$$
$$CO_2 + C = 2\,CO$$
$$H_2O + C = CO + 2\,H$$

The resulting producer gas has about the following composition:

Nitrogen,	60.3 per cent
Carbon Monoxide,	22.8 per cent
Carbon Dioxide,	5.2 per cent
Oxygen,	0.4 per cent
Hydrogen,	8.5 per cent
Hydrocarbons,	2.8 per cent

In running the producer, there is a heat loss of about 35 per cent, principally in radiation, ashes, latent heat, decomposition of steam, and sensible heat of gas. Another producer, the Taylor Producer, has in place of the grate-bars a revolving dome-shaped plate, through which air is driven into the center of the fire. In place of the brick lining this producer has a water-jacket. Bituminous coal is the fuel generally used in these producers. As this gas contains about 60 per cent nitrogen, it is weak fuel. In a few localities natural gas, a stronger fuel, is obtained. A gas made of vaporized petroleum mixed with dry steam and forced through a red-hot metallic retort, is used in the Archer process.

SPECIAL STEELS.

Nickel Steel. Nickel steel is made by adding metallic nickel, nickel ore, or ferro-nickel, to the bath of the open-hearth process. The nickel increases its density, elasticity and strength. This steel is used for armour plate, on account of these qualities, and also because it does not corrode. Nickel steel contains about 4 per cent nickel, .3 per cent carbon, .7 per cent manganese, and .02 per cent phosphorus. For such uses as bicycle tubes, shafts, axles, etc., the high elastic limit of nickel steel tends to prolong indefinitely the life of the piece, and because of its superior toughness, offers greater resistance to sudden strains and shocks.

Aluminum Steel. From .05 per cent to .1 per cent aluminum in steel castings reduces the melting point, prevents blowholes, and keeps the metal liquid while being poured. Aluminum gives no increase of hardness.

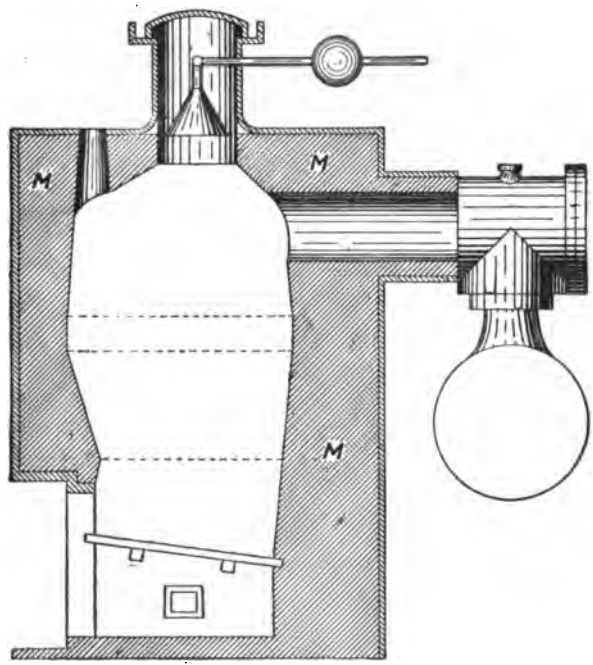


Fig. 11.

Chrome Steel. If chromite is melted in brasque crucibles with charcoal, the result, ferro-chrome, which has 40 per cent chrome and 48 per cent iron, is used in making chrome steel, by melting it with bar iron in crucibles. Chrome, like manganese, hardens iron. It also makes it more forgeable. It is used, on account of its hardness, for burglar-proof safes, but it is not entirely satisfactory, and other steels are fast driving it out. It has about the following composition: chromium, .5 per cent to 3 per cent; carbon, .5 per cent to .9 per cent.

Manganese Steel. Manganese steel is an alloy of iron and manganese, containing a considerable proportion of carbon. If

there is a very small portion of manganese, the effect is slight. As the proportion of manganese rises above 2.5 per cent the strength and ductility diminish, while the hardness increases. This hardening effect is a maximum with about 6 per cent manganese. Above this the strength and ductility both increase, and at 14 per cent of manganese the metal is so hard that it is difficult to cut with steel tools. It welds with great difficulty, but it can be forged. Its toughness increases by quenching from a yellow heat. It has a remarkable combination of great hardness, which cannot be lessened by annealing, great tensile strength, toughness and ductility. The fact that it cannot be machined, on account of its hardness, limits its usefulness. It is used principally for car-wheels, dies and crusher-jaws.

Tungsten Steel. Steel containing a little carbon and tungsten is much harder than steel with carbon alone, and yet not very brittle. A specimen from Sheffield, England, for chisels, used untempered to turn chilled rolls, was not brittle, yet it was hard enough to scratch glass. It contained 9.8 per cent tungsten, .7 per cent silver and .6 per cent carbon. In working this metal it has to be given its final shape by hammering at red heat, and if the percentage of tungsten is high it is necessary to reheat it while it is being hammered. After the desired shape is reached the hammering must be continued, with numerous blows, until it becomes nearly cold. Tungsten is employed to produce steel of moderate hardness, with great toughness, resistance and ductility. Its principal use is for cutting-tools. It is self-hardening.

CASE-HARDENING.

By the process called case-hardening, a thin layer of steel is formed over the iron. To do this, iron is heated to redness, and powdered potassic ferro-cyanide $K_4Fe(CN)_6$, is sprinkled over the surface. When suddenly cooled, the surface of the iron is hard enough to resist a file. The chemical reaction which takes place is

$$K_4Fe(CN) = 4KCN + FeC_2 + N_2.$$

THE HARVEY PROCESS.

The Harvey process for making armor plate is somewhat like case-hardening. The outside of the heated steel plate is cov-

ered with charcoal, from which it absorbs carbon in the same manner as wrought iron absorbs carbon in making cement steel. The layer of hard steel thus formed is further hardened by quenching with water. This makes a plate with an exceedingly hard surface, which breaks up shot and shell. The backing is, however, tough, mild steel.

THE EFFECTS OF THE ELEMENTS IN STEEL.

The following from Howes' Metallurgy of Steel will give an idea of the effects of the elements:

Carbon. Carbon up to 1.5 per cent increases Tensile Strength, Compressive Strength, and raises the Elastic Limit; decreases the malleability and welding power.

Silicon. Silicon increases hardness, Tensile Strength and solidity, and prevents blow-holes. Too much silicon makes steel brittle. From .3 per cent to .5 per cent should be the maximum.

Sulphur. Sulphur causes hot shortness; that is, the metal is brittle when hot, both under the hammer and rolls.

Arsenic has the same effects as sulphur.

Phosphorus causes cold shortness. It makes steel hard and liable to break. It increases the Elastic Limit and reduces Elongation.

Manganese prevents hot shortness and blow-holes, removes or offsets the effect of sulphur. It increases Toughness, Elongation and Tensile Strength. Too much manganese makes steel brittle when cold, especially after quenching.

Copper. Copper causes red shortness; .5 per cent may be allowed in rails, but 2 per cent makes steel worthless. Tin steels are not forgeable or ductile, either hot or cold.

TEMPERING.

Tempering steel is the process of giving it, after it has been shaped, the necessary hardness to do its work. A piece of steel after it has been properly tempered should be finer in grain than the bar from which it was made.

This is accomplished by first hardening the piece, usually harder than necessary, and then toughening it by slowly heating and gradually softening, until it is just right for the work. The

process is as follows: The tool to be tempered is heated to a cherry red, and plunged into cold water or oil to a depth somewhat above the cutting edge. When this portion has become entirely cold, the piece is taken out and the cold end polished, usually with emery-cloth; the point is now too hard and brittle. The heat contained in the hot portion gradually enters by conductivity into the quenched part, and as it does so, colors are formed which denote temperature. The colors seen in order are pale yellow, straw, brownish yellow, light purple, dark purple, blue. They are formed by oxide on the surface. These colors run from the hot portion to the cutting edge, and when the proper color reaches the cutting edge, the whole piece is quenched. Some tools are of such a shape that the temper must be "drawn" to the desired color by reheating the piece between hot plates or in a hot iron ring.

The following list will give some idea of the colors, temperature and hardness of tools:

Very pale Yellow, temperature about 430° F.	Steel-engraving Tools. Turning Tools. Hammer Faces. Planer Tools. Wood-engraving Tools.
Straw Yellow, temperature about 460° F.	Dies. Taps. Drills. Punches. Reamers.
Brown Yellow, temperature about 500° F.	Gouges. Plane Irons. Twist Drills. Cooper Tools. Wood-boring Cutters.
Light Purple, temperature about 530° F.	Augers. Surgical Instruments. Cold Chisels. Edging Cutters.
Dark Purple, temperature about 550° F.	Axes. Gimlets. Needles. Hack Saws. Screwdrivers. Springs. Wood Saws.

COPPER.

As copper occurs in the metallic state, it was one of the earliest known metals. The native copper deposits of the Lake Superior region were worked by prehistoric inhabitants. Copper compounded with tin was the metal of the Bronze Age. With the exception of iron, copper is our most useful and important metal.

ORES.

The native copper of Lake Superior is still an important source of supply, but by far the largest quantity is obtained from the sulphide ores, of which Copper Pyrites (Cu_2 S. Fe_2 S_3) is the most important. When pure it contains 34.6 per cent of copper, 30.57 per cent iron and 34.9 per cent sulphur, but the average ore carries only about 12 per cent of copper. Spanish iron pyrites is another source of supply; it is first used in the manufacture of sulphuric acid, after which the copper is extracted from the "cinder." It contains only 3 or 4 per cent of copper, but carries also a small proportion of gold and silver, which makes it a profitable ore.

Carbonate ores, formed by the weathering of the sulphides are now about exhausted, as they occur only a short distance below the surface.

EXTRACTION.

There are two main processes for extracting copper from its ores:

(1) Process involving fusion.

(2) Wet process used for low-grade ores.

The most important fusion method is the "Welch" or "Reaction" process. The prepared sulphide ore is first roasted in heaps, kilns or a reverberatory furnace. Care is taken that not too much of the sulphur is expelled. Next, this calcined ore is fused in a reverberatory furnace. The copper has a greater affinity for the remaining sulphur than any of the other metals, and copper sulphide is formed.

$$Cu_2O + FeS = Cu_2S + FeO.$$

The ferrous oxide (FeO) and the silica unite and form a slag, which carries away lime or other impurities present. The cuprous sulphide Cu_2S combines with the excess of iron sulphide

left in the charge, forming a fusible substance called a "regulus," or first copper matte, which contains about 30 per cent of copper. This first matte is again roasted and fused, and part of the iron slagged away as before, leaving the second matte, which contains about 50 per cent, if "blue metal" is wanted, or 75 per cent of copper, if "white metal" is being made. A small amount of metallic copper is also produced. These copper bottoms contain most of the impurities, including much of the gold and silver.

In a third reverberatory furnace the second matte is again partly oxidized and then fused, the product this time being crude metallic copper and a slag rich in copper. The rich slags from the first and second matte are worked up for their copper. The reactions by which metallic copper is produced are:

(1) $2Cu_2O + Cu_2S = 6Cu + SO_2$

(2) $3Cu_2O + FeS = 6Cu + FeO + SO_2$

The SO_2 gas passes away and the FeO goes into the slag.

Producer gas is used for heating the furnaces in modern plants.

CUPOLA SMELTING.

In the first stages of this process the chemical action is about the same as the "Welch" method. A first and second "Matte" is produced in small water-jacketed blast furnaces of rectangular sections using cold blast. (See Fig. 12.) Some "black copper" is produced with the second matte.

The second matte, called "white metal," is now completely roasted to oxide. This oxide of copper is reduced to metallic copper in a blast furnace by CO gas in the same manner as in the production of iron.

The reaction is

$$Cu_2O + CO = 2Cu + CO_2$$

The fuel is coke or charcoal. The slag from the first matte is thrown away, but the other slags go back into the process.

Less skilled labor is necessary in the cupola method and less fuel is required. It is consequently in favor in remote regions. The metal of oxidized ores (carbonates) can be extracted by this process in one operation. The reverberatory method produces purer copper, and must be used when there is much antimony and

arsenic in the ore. Highly refractory ores, which are difficult to fuse in a blast furnace, can be better treated in reverberatories, as the slag can be skimmed off in a partly melted condition.

The variations in the foregoing processes are numerous. A common American practice is to use the cupola for obtaining the first matte, and finish the process in reverberatory furnaces.

Modified Bessemer converters are now successfully used to convert copper matte into crude copper. The converter has the tuyeres in the sides, and is lined with silica and clay. As the

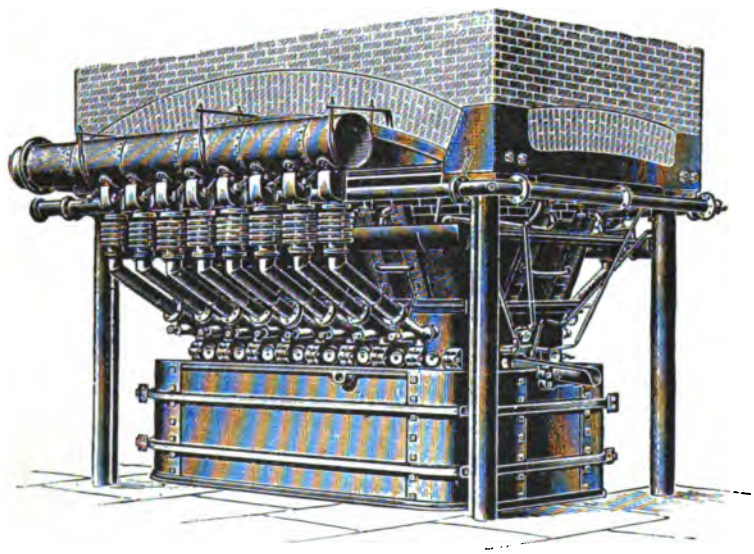


Fig. 12.

wear on the lining is very great, provision is made for quickly replacing a worn-out converter by one which has been relined. Mattes containing from 30 to 60 per cent copper have been thus successfully treated at a considerable saving of expense.

REFINING.

The crude copper produced by any of the foregoing methods is refined in a reverberatory furnace with a large hearth. It is slowly melted down with an excess of air. The impurities oxidize first and form a slag with the silica from the lining of the furnace. This slag is frequently skimmed off. The copper finally begins to oxidize, forming Cu_2O, which acts on any Cu_2S,

forming SO_2, which causes the molten metal to boil. When this action ceases, the copper contains too much copper oxide. This is reduced by "poling." Poles of green wood are thrust into the bath, and the distilled hydrocarbon gases cause the bath to boil, which expels any SO_2 gas remaining. Charcoal is spread over the molten metal, which, with the hydrocarbon gas, removes the oxygen from the Cu_2O, leaving metallic copper. Samples are taken out from time to time, and when the color changes from red to flesh color, and the sample becomes fibrous with silky lustre and can be bent double, the refining is finished. The rich slags go back into the process. A little oxide of copper is left in the metal, as it neutralizes the effect of the small amount of remaining impurities.

The metal is then run into small moulds. An ingot "under poled," containing too much oxide, will show a furrow along its surface. An ingot with the right proportion will have a flat surface, called "tough pitch," and one which is "over poled," containing too little oxide, will show a ridge.

Electric refining is fast replacing this older method. In the United States two-thirds of the product is thus refined. By the electrical method all the gold and silver in the copper is recovered, and the copper produced is very pure. The crude copper is cast into slabs as it runs from the furnace. A row of slabs is placed in a tank containing a solution of copper sulphate made acid with sulphuric acid. These form the dissolving plates, and opposite each is placed a thin sheet of pure copper. The tanks are connected in series by wires and the current passed through. The electric current causes the crude copper to dissolve and pure copper to be deposited on the thin plates. The gold and silver, together with other impurities, fall to the bottom as mud or "slimes," from which the precious metals are extracted by chemical processes.

The *wet process* is used for lean ores. It has the advantage of extracting at the same time any gold and silver present. This process involves getting the copper and precious metals into solution either as sulphate or chloride and then the copper is precipitated by electrolosis, metallic iron or quicklime.

The solutions are produced either by dissolving in the dilute

acids or roasting the sulphide to sulphate or by roasting with salt to obtain the chloride and then leaching with water.

PROPERTIES OF COPPER.

Copper is a rather soft metal and is very ductile and malleable. It can be worked both hot and cold, but should not be heated too hot, as it crystallizes and takes up oxygen. When worked cold it is stronger and harder, but less ductile. Heating and quenching make it softer. Rolled sheet copper has a tensile strength of from 24,000 to 28,000 pounds per square inch, and annealed wire over 40,000 pounds per square inch. Good castings cannot be made from pure copper because they contain blowholes and the shrinkage is too great.

Copper is not affected by the weather, but in damp places it is slowly corroded; carbonate of copper, called verdigris, being formed by the carbonic acid of the air.

The thermal conductivity of copper is high.

The electrical conductivity of good copper is but little less than that of silver, and is about six times that of iron. A very small amount of impurity reduces its electrical conductivity as much as 10 per cent. Antimony is the most harmful impurity from a mechanical standpoint, and should not be over .02 per cent.

The growth of electrical industries has greatly increased the demand and price of copper of late years. It is estimated that 60 per cent of the world's production of copper is consumed in electrical work. The United States produces over 55 per cent of the world's output of copper, or over a quarter of a million long tons annually.

LEAD.

The most important ore of lead is Galena, lead sulphide (PbS). In the United States it is found in the upper valleys of the Mississippi and Missouri Rivers and in the Rocky Mountains. The mines of Spain, Germany and England furnish the bulk of the European product. It occurs in bright, shining, cubic crystals of metallic lustre. When pure it contains 86.6 per cent of lead. Galena usually contains silver, and frequently a small amount of gold. It is associated with sulphides of zinc, antimony, copper and iron. As it is a very heavy mineral it is easily concentrated.

Cerussite — lead carbonate, $PbCO_3$, — is an ore of some importance and is mined in Leadville, Colorado.

SMELTING.

Lead ore is smelted either in reverberatory furnaces or blast furnaces. When using the reverberatory furnace with sulphide ore, the chemical action whereby lead is produced is much the same as in the final stage of copper smelting in the "Welch" method. The ore is partially oxidized to lead oxide, PbO, at a low heat, some sulphate, $PbSO_4$, also being formed. Then the temperature is raised and the lead is produced according to the following reactions:

(1) $PbS + 2PbO = 3Pb + SO_2$

(2) $PbS + PbSO_4 = 2Pb + 2SO_2$

The lead as it is formed runs into a pot, and the operation is repeated until no more lead can be extracted, when it is tapped and the slag withdrawn in a pasty condition. This "gray slag" is usually smelted in a blast furnace for the lead it still contains. This method is simple and the apparatus inexpensive, but its use is limited to high-grade ores containing 60 per cent to 70 per cent of lead, and only 4 or 5 per cent silica. The process requires much fuel and skilled labor.

SMELTING IN A CUPOLA OR BLAST FURNACE.

This process is used for all ores containing over 4 per cent silica, for carbonate ores, and for various lead slags and drosses obtained in purifying the crude lead.

The Furnace is built of brick and lined with fire brick. It is usually oblong in section. The shaft is from 14 to 20 feet high and tapers downward to the boshes, which taper more sharply to the crucible. The section at the crucible is usually about 12 feet by 3 feet 6 inches. The tuyeres, 6 or 8 in number, are placed on each side, near the top of the crucible. The boshes and part of the crucible are cooled by cast or wrought iron water jackets. The furnace is charged through a door in the side, near the top.

As lead is somewhat volatile, provision must always be made for collecting the lead fumes. Various devices have been tried, but long flues, wherein the fumes condense and settle, are most

commonly used. The top of the furnace is connected with one of these flues.

The sulphide ores are roasted in a reverberatory furnace or in hand or mechanical kilns. The roasted ore is charged into the blast furnace with suitable fluxes and various mixtures of coke, charcoal and coal as fuel. Iron plays an important part in the smelting, as it is capable of decomposing silicate of lead and is added as an iron slag or as ore if not present in correct amount.

In smelting there is usually a small amount of matte formed, consisting of sulphides of iron, copper, nickel and lead. This is tapped with the slag into a slag pot, where it rises to the top and is separated when the mass cools. The matte is broken up and roasted and its lead and copper recovered. The lead collects in the crucible and is tapped out at intervals.

SOFTENING AND DESILVERIZING.

The lead obtained by either the reverberatory or blast furnace method contains copper, arsenic, antimony and other metals in addition to silver. The impure lead is slowly melted down in a reverberatory furnace. The lead, having a lower melting point than the impurities, liquefies first, leaving a residue containing the copper and part of the arsenic and antimony. The lead is next heated very hot with an excess of air, and then most of the remaining impurities oxidize and form a scum, which is skimmed off. The silver remains with the softened lead and is extracted by the Park's Process. This process depends upon the fact that a small percentage of zinc added to the molten lead will collect all the gold and silver to form an alloy, which, being of less specific gravity, rises to the top, and having a higher melting point solidifies before the lead.

From the softening furnace the molten lead is run directly into a large kettle. Here from 1 to 3 per cent of zinc is added to three successive portions. After each addition the mass is well stirred and then allowed to cool somewhat, when a crust is formed, which is removed. The first crust contains most of the gold and is called the gold crust. The second crust is called the silver crust, and the third crust, containing the silver that still remains, is used for the first addition to the next charge.

RECOVERY OF THE SILVER AND GOLD.

The gold and silver crusts are melted slowly in a kettle or reverberatory furnace, and most of the lead mixed with the crust melts out and is recovered. The zinc is distilled off in large graphite retorts, leaving a small amount of lead, which contains all of the silver and gold. The lead is separated from the precious metals by cupelling. In the cupelling furnace the lead is oxidized to litharge (PbO), leaving the metallic silver and gold. The furnace has a hearth made of porous material, which absorbs part of the melted litharge as it forms; the remainder runs into a pot. The litharge is ground and sold if it does not contain too much silver, in which case it is smelted again. About 60 per cent of zinc is recovered in metallic form and is used again in the desilverizing kettle.

REFINING THE DESILVERIZED LEAD.

The desilverized lead contains .6 per cent to .7 per cent of zinc, which is removed in a reverberatory furnace or large kettle. The charge is heated very hot in the reverberatory, and the zinc in part volatilizes; then the doors are opened and the remainder of the zinc is oxidized, and with some lead oxide is skimmed off. This is repeated until the zinc is entirely removed.

When refined in a kettle, steam is forced into the molten charge; the zinc and a little lead oxidize and form a scum, which is skimmed off.

The desilverized and refined lead is run into iron molds on wheels, and when cooled is ready for the market. The amount of marketable lead obtained is about 80 per cent of the impure lead. By using the Howard "stirrer," "skimmer" and "press" for the gold and silver crusts, 85 per cent has been obtained and 70 per cent of the zinc recovered.

An older process for desilverizing lead is the Paterson Process. It is found that when molten lead is cooled slowly, crystals of lead form which contain less silver and other impurities than the remaining molten mass. By repeated crystallization the silver is concentrated in a portion of the lead, and the remainder is almost free from silver. The silver-bearing portion, which must be cupelled, is about 30 per cent of the whole against 5 per cent in

the Park's Process. The Paterson Process is not used in the United States.

The working up and recovery of all the by-products formed in the smelting of lead is a very important and very complex part of the process.

PROPERTIES OF LEAD.

Lead is the softest and heaviest common metal. It is very malleable and ductile, but has little tenacity. Lead is insoluble in sulphuric acid of moderate strength and is not much affected by cold hydrochloric acid. It is used in chemical works in the manufacture of sulphuric acid and for other purposes. Ordinary water has little effect on lead. Pipes used for conveying water are soon covered with a thin layer of carbonate and sulphate of lead, which is insoluble and prevents further action.

Water from swamps, etc., however, dissolves small amounts of lead, which makes its use dangerous for domestic purposes. Water from new pipes or pipes which are not kept constantly full should not be used for household purposes, because of danger from poisoning.

Lead is not affected by dry air, but is slowly corroded in moist air.

TIN.

This metal was known to the ancients, and very successfully used by them for hardening copper. The most important ore is tin-stone, $Sn\,O_2$, and the principal mines are in Cornwall, England, and Banca in the East Indies.

The smelting is conducted in a reverberatory furnace. The concentrated ore, mixed with finely divided anthracite coal and with a little lime is heated on the bed of the furnace. The tin is produced and runs into the depressed center of the furnace, from which it is tapped and cast into pigs. This impure tin is refined by liquating and poling.

PROPERTIES AND USES.

Tin is white in color with a slightly yellowish shade. It has a peculiar odor, and when bent it gives out a crackling sound known as the "tin cry." It has little tenacity, considerable ductility, and is very malleable. It can be worked at about the

boiling point of water, but becomes very brittle at 400° F. It can be rolled into very thin sheets; tinfoil being sometimes only one-thousandth of an inch thick. On account of its ductility it is readily made into tubes, wire, etc.

The bulk of this metal is used for tin plate. Thin sheets of mild steel are carefully cleaned and annealed and then dipped in a bath of molten tin covered with a layer of tallow. They are then passed through rolls to remove the superfluous tin, leaving a very thin coating of pure tin on both sides of each sheet. Tin plate finds numerous uses in the canning industries, for household utensils, etc.

Almost all of the remaining product is used for making alloys of tin, and only a comparatively small amount is used for pipes, sheets, etc., on account of the high price of this metal.

ZINC.

A large proportion of this metal is obtained from the ore called Zinc Blend, ZnS; the carbonate and silicate are also important ores, and considerable zinc is obtained from Franklinite.

In the metallurgy of zinc advantage is taken of the volatility of this metal. It can be distilled unchanged at 1040° F. The ore is roasted to oxide of zinc, ground and mixed with finely divided fuel and heated to a bright red in gas heated retorts. The carbon takes the oxygen from the zinc oxide, forming CO gas, and the zinc is set free and distills off. It is condensed in iron tubes which are kept at such a temperature that the zinc remains liquid and runs into a receiving vessel.

This zinc contains iron and other impurities, and is purified by redistillation. It comes on the market cast in slabs, and in this form is called "spelter."

PROPERTIES AND USES.

Zinc is a bluish white metal, brittle and crystalline. It is quite ductile at a temperature of 248° F., but is so brittle at 390° F. that it can be crushed to powder.

Zinc is readily dissolved by acids and alkalies, but is not affected by the weather. It is very largely used for galvanizing iron, which is done by dipping the carefully cleaned iron in a bath of molten zinc, using sal-ammoniac as a flux. Zinc protects

the iron from oxidation, and is effective as long as any zinc remains on the iron, being the reverse of the action of tin plate which causes the iron to rust more quickly as soon as there is any flaw in the coating. Zinc is also used in making alloys and for batteries, sheets for roofing, etc.

ALUMINUM.

Aluminum has recently been transferred from a rare metal to one which, bulk for bulk is no more expensive than copper, by an electrolytic process invented by Hall. Beauxite, a hydrated oxide of aluminum is the important source of supply. Hall's process is conducted in a graphite lined vessel, and depends upon the property of cryolite — a double fluoride of sodium and aluminum, of dissolving oxide of aluminum. Cryolite melts at about 900° F. and then becomes a conductor of electricity. The bath is kept in a molten condition by a heavy current of electricity of low voltage. The oxide of alumina is sprinkled on the top of the bath and quickly dissolves, and is reduced by electrolysis to metallic aluminum which settles in the bottom of the crucible, from whence it is drawn from time to time.

If pure aluminum is desired the oxide of alumina used is obtained by a chemical process from beauxite.

PROPERTIES AND USES.

Aluminum is a grayish white metal, very malleable and ductile, and is a good conductor of both heat and electricity. It is acted on but feebly by sulphuric or nitric acid or by the organic acids. It is, however, dissolved by hydrochloric acid and the alkalies. Its most remarkable property is its extreme lightness, it being only about one-third as heavy as iron. It is fairly strong and imparts great tensile strength to its alloys. Good castings can be made from it, although the shrinkage on cooling is considerable. It can be worked cold, and is readily formed into sheets, wires, tubes, etc.

It is replacing copper to some extent as an electrical conductor, and is used for making a high class of kitchen utensils and a great variety of small ornamental articles. One objection to its use for some purposes is that it can be soldered only with difficulty.

Aluminum has not fulfilled the enthusiastic prophecies which were made when it became a common metal. Among the reasons for this may be mentioned its low tensile strength and unreliability. It is not as strong, weight for weight, as steel, and is too soft to resist wear. Again, continued shocks render it crystalline and brittle; consequently unreliable. Its expansion and contraction for heat and cold is considerably greater than in the case of copper, and great care must be taken in putting up lines of wire made of this metal. It is more easily corroded by sea water than copper; and its position in the electrical scale of metals is such that when any other metal comes in contact with it the aluminum is corroded.

The table on page 49 gives in a condensed form some of the more important properties of common metals. This table is a great aid in making calculations for weights, strength, etc., and also gives an idea of the relative cost. Many of the various properties are subject to some variation. The specific gravity varies with the percentage of foreign substances, and also with the process of manufacture, that is, whether the metal has been rolled, hammered or cast. The melting points of commercial metals are also somewhat variable.

TABLE OF METALS.

Name.	Specific Gravity.	Melting Point. Fahrenheit.	Electrical Conductivity. Silver = 100.	Heat Conductivity. Silver = 100.	Tensile Strength. lbs. per sq. in.	Weight per cu. in. in lbs.	Weight per cu. ft. in lbs.	Approximate Price per pound in Pigs, Billets, etc., 1902.
Cast iron	7.0 to 7.7	2100°	12.0	11.4	13,000 to 30,000	.260	445	¼¢
Wro't Iron	7.4 to 7.8	3000°	16.0	11.9	40,000 to 60,000	.278	485	1¼¢
Steel 0.1% C.					50,000 to 65,000			
" 0.2% "					60,000 to 80,000			
" 0.4% "	7.6 to 7.8	2500°	12.0	11.6	70,000 to 100,000	.283	490	1½¢
" 0.6% "					90,000 to 120,000			
Copper	8.8 to 8.9	1930°	99.9	73.6	25,000 to 50,000	.320	555	14¢
Lead	11.2 to 11.4	620°	8.3	8.5	1,600 to 2,400	.410	709	4½¢
Tin	6.9 to 7.3	446°	15.0	14.5	3,000 to 5,000	.263	455	25¢
Zinc	6.8 to 7.2	774°	29.0	19.0	5,000 to 20,000	.258	446	4¼¢
Aluminum	2.56	1100°	63.0	38.0	12,000 to 23,000	.093	160	30¢
Bronze	8.7	1550°	6.5		29,000 to 60,000	.313	541	20¢
Brass	8.4		22.0	23.6	30,000 to 40,000	.300	519	13¢

ALLOYS.

Mixed metals give us alloys, many of which possess useful and valuable qualities not found in the pure metals. The ancients were skilled in making bronze and brass, and many of their products cannot be surpassed at the present day.

In general the alloys of copper with tin are known as bronze, and with zinc as brass, but zinc is frequently added to bronze to cheapen it or change the color, and tin is often added to brass to harden it, so that the line between them cannot be sharply drawn.

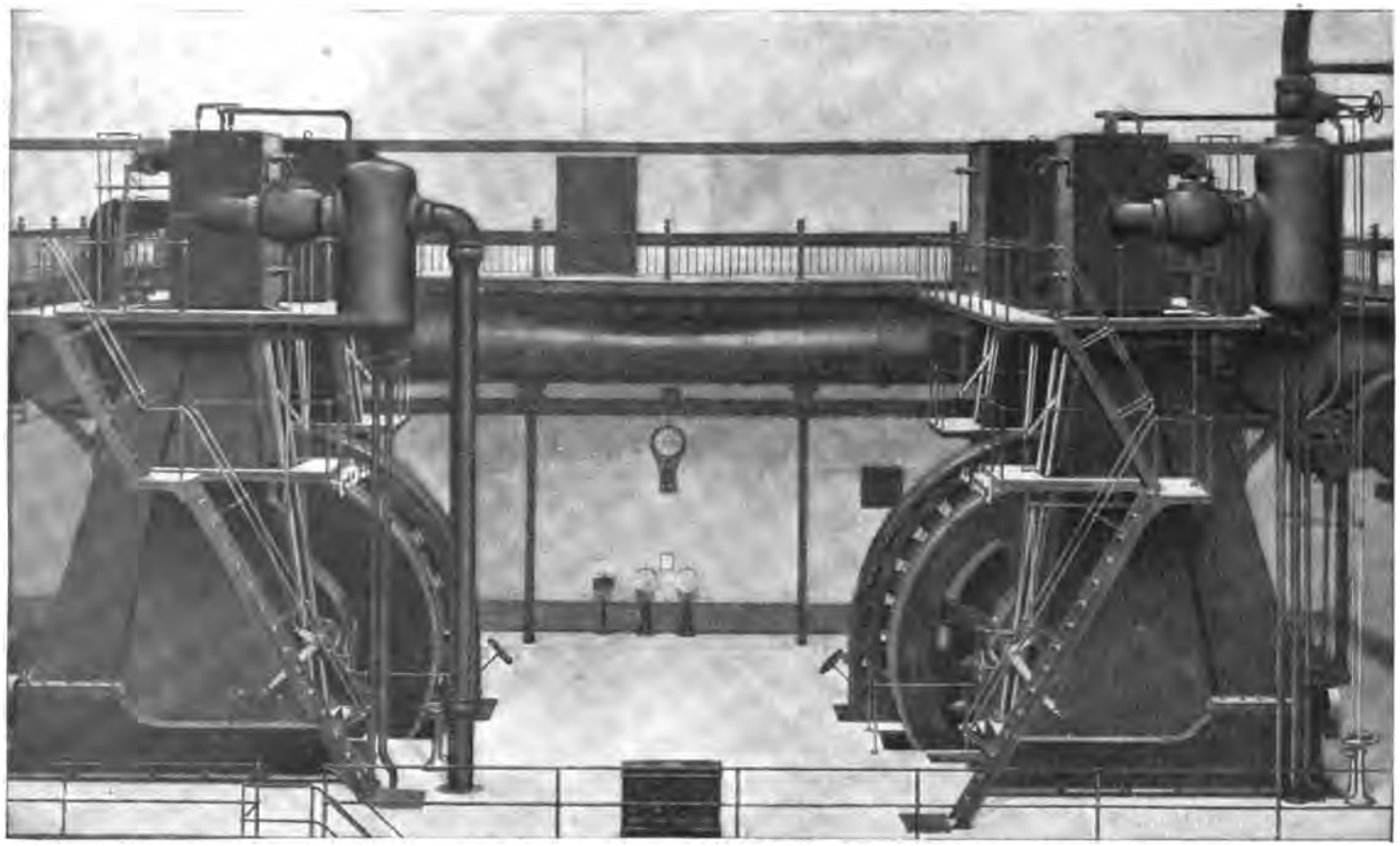
There are countless combinations of metals, but only a few are of general importance. The table given includes most of these with their approximate composition, although each foundry has its own special mixtures. In making alloys, the most infusible metal is melted first, and the others are dropped into the crucible in small lumps, the most volatile being added last. A layer of charcoal is frequently thrown on the surface of the metal to prevent oxidation. In many alloys the metals begin to separate on standing, in which case it is necessary to mix well and pour at as a low temperature as possible, so that the casting will solidify quickly. This is helped by casting in iron moulds. Some metals can not be alloyed in all proportions; thus copper will take up only a small proportion of lead.

To produce finest quality alloys only pure metals can be used, as small amounts of impurities have a very decided effect, just as in the case of iron and copper. The method of making is also important in determining the quality of an alloy. In general alloys which are to be worked into sheets, tubes and wires must be more pure than those required for castings. A small proportion of lead is said to help the rolling qualities of brass, and a very small percentage of phosphorus in bronze makes it more fluid and free from blow holes. The alloys of metals with mercury are called amalgams. One method of extracting metallic gold from its ores is amalgamation, and the effect of amalgamating the zinc in batteries is well known. Formerly alloys were thought to be chemical combinations of metals, but now it is generally considered that they are simply mixtures of metals, sometimes being solidified solutions in each other.

TABLE OF ALLOYS.

Approximate Percentage Composition by Weight.

Name.	Copper.	Tin.	Zinc.	Lead.	Other Metals.	Uses and Remarks.
Gun metal	91	9				Ordnance, bearings, castings
Bell metal	75	25				Bells, gongs; rather brittle
Bronze coin	95	4	1			Coins, medals
Phosphor bronze	92½	7			½ Phosphorus	Strong castings, heavy bearings
Manganese bronze	89	10			1 Manganese	Propeller blades, pumps. It is non-corrosive and very strong
Aluminum bronze	90				10 Aluminum	Very high tensile strength
Valve metal (best)	88	12	2			Sometimes called "composition"
Valve metal	83	2	15			Cheaper valves, cocks, etc.
Bearing metal	77	8		15	Trace of Phosphorus	Heavy bearings, used on railroads
Brass (common)	66⅔		33⅓			Sheets, wire, tubes, pipe fittings
Muntz metal	60		40			Bolts, nuts; malleable at red heat
Delta metal	56		42		2 Iron	Strong sheets, etc: "Tobin bronze" is a delta metal with a little tin and lead added.
Brazing metal (soft)	50	12½	37½			Low melting point
Brazing metal (medium)	50		50			For copper work
Brazing metal (hard)	75		25			Strongest
German silver	60		20		20 Nickel	Ornaments, resistance wire; composition variable
Fusible plug		10		86	4 Bismuth	For steam boilers
Common solder		50		50		
Fine solder		66⅔		33⅓		
Babbitt's metal	3	89			8 Antimony	The original Babbitt; for bearings
Babbitt's metal				80	20 Antimony	Commonly called Babbitt; used for repair work on bearings
Pewter		80		18	2 Antimony	Plates, mugs, etc.; composition variable
Britannia metal		90			10 Antimony	Table wear, ornaments; composition variable
Type metal				80	20 Antimony	Type and lithograph
Regulus metal				88	12 Antimony	Acid cocks, valves, etc. Sometimes called white metal.



2400 HORSE-POWER VERTICAL CROSS COMPOUND ENGINES, BUILT BY McINTOSH, SEYMOUR & CO., WITH DIRECT-DRIVEN ELECTRIC GENERATORS.

SECTION 3.

THE STEAM ENGINE.

PART I.

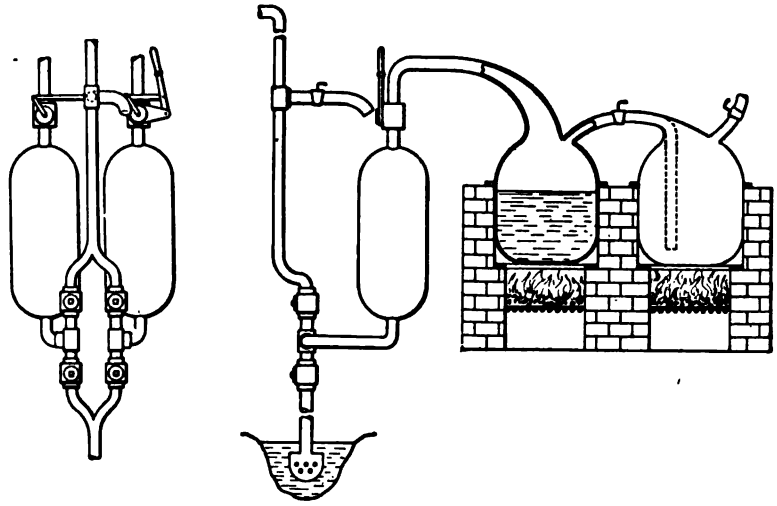
There are various kinds of engines from which mechanical work is obtained by the expenditure of heat. In the gas engine a mixture of gas and air is burned in the cylinder, the heat thus generated being converted into work by the expansion of the products of combustion. The action in oil and hot-air engines is very similar. The most important of all heat engines, however, is the steam engine, in which the heat in steam is transformed into work. It will be useful to review briefly some of the stages through which it has passed in its development.

The first steam engines of which we have any knowledge were described by Hero of Alexandria, in a book written two centuries before Christ. Some of them were very ingenious, but the best were little more than toys. From the time of Hero until the seventeenth century there was very little progress. At this time there began to be great need of steam pumps to remove water from the coal mines. In 1615, Salomon de Caus devised the following arrangement. A vessel, having a pipe leading from the bottom, was filled with water and then closed. Heat applied to the vessel caused steam to be formed, which forced the water through the pipe.

A little later an engine was constructed in the form of a steam turbine; but it was unsuccessful, and the attention of inventors was again turned to pumps.

Finally Thomas Savery completed, in 1693, the first *commercially successful* steam engine. It was very wasteful of steam as compared with our engines of today, but as being the first engine to accomplish its task it was a grand success. Savery's engine (Fig. 1) consisted of two oval vessels placed side by side and in communication with a boiler. The lower parts were connected by tubes fitted with suitable valves. Steam from the boiler was admitted to one of the vessels and the air driven out. The steam was then condensed and a vacuum formed by letting

water play over the surface of the vessel. When the valve opened, this vacuum drew water from below until the vessel was full. The valve was then closed and steam again admitted, so that on opening the second valve the water was forced out through the delivery pipe. The two vessels worked alternately. When one was filling with water, the other was open to the boiler and was being emptied. Of the two boilers, one supplied steam to the oval vessels and the other was used for feeding water to the first boiler. The second boiler was filled while cold and a fire lighted under it. It then acted like the vessel used by Salomon de Caus and forced a supply of feed water into the main boiler.



END VIEW. Fig. 1. SIDE VIEW.

A modification of Savery's engine, the pulsometer (Fig. 2), is still quite common. It is used in places where an ordinary pump could not be used and where extreme simplicity is of especial advantage. Its valves work automatically and it requires very little attention.

A serious difficulty with Savery's engine resulted from the fact that the height to which water could be raised was limited by the pressure which the vessels could bear. Where the mine was very deep it was necessary to use several engines, each one raising the water a part of the whole distance. The consumption of coal

in proportion to the work done was about twenty times as great as that of a good modern steam engine. This was largely, though not entirely, due to the immense amount of steam which was wasted by condensation when it came in contact with the water in the oval vessels.

The next great step in the development of the steam engine was taken by Newcomen, who in 1705 succeeded in preventing contact between the steam and the water to be pumped, thus diminishing the amount of steam uselessly condensed. He introduced the first successful engine which used a piston working in a cylinder.

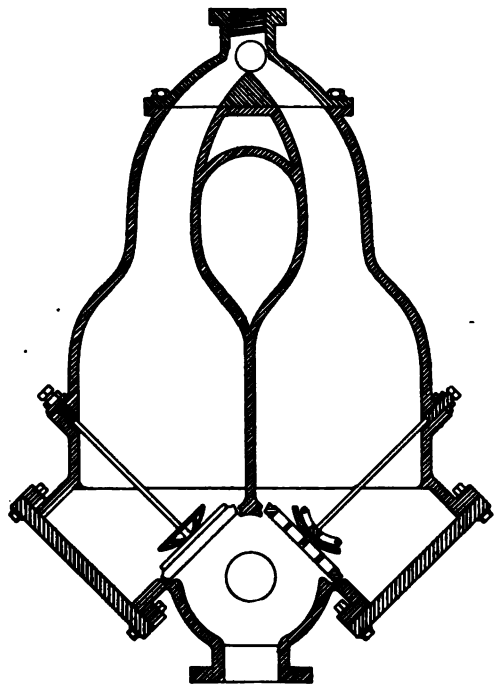


Fig. 2.

In Newcomen's engine, shown in Fig. 3, there was a horizontal lever pivoted at the center and carrying at one end a long heavy rod which connected with a pump in the mine below. A piston was hung from the other end of the lever, and worked up and down in a vertical cylinder, which was open at the top. Steam acted only on the lower side of the piston. Steam at atmospheric pressure was admitted from the boiler to the cylinder, and as the pressure was the same both above and below the piston, the falling of the heavy pump rod raised the piston. A jet of water was now passed into the cylinder to condense the steam and form a vacuum. This left the piston with atmospheric pressure above and very slight pressure below, so it was forced down and the pump rod again raised. Steam could again be admitted to the cylinder, the pump rod would fall, and so on indefinitely.

In the days of Newcomen it was very difficult to obtain good workmanship. For this reason it was often necessary to make the cylinders of wood, and even then there might be a space of one-eighth of an inch between the wall of the cylinder and the piston. In order to prevent steam from blowing through this passage, or air from leaking in when the steam was condensed, it was customary to keep a jet of water playing on the top of the piston.

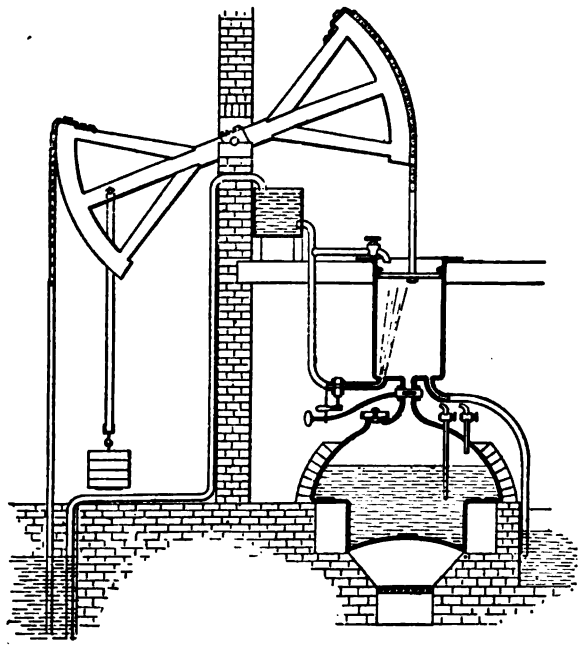
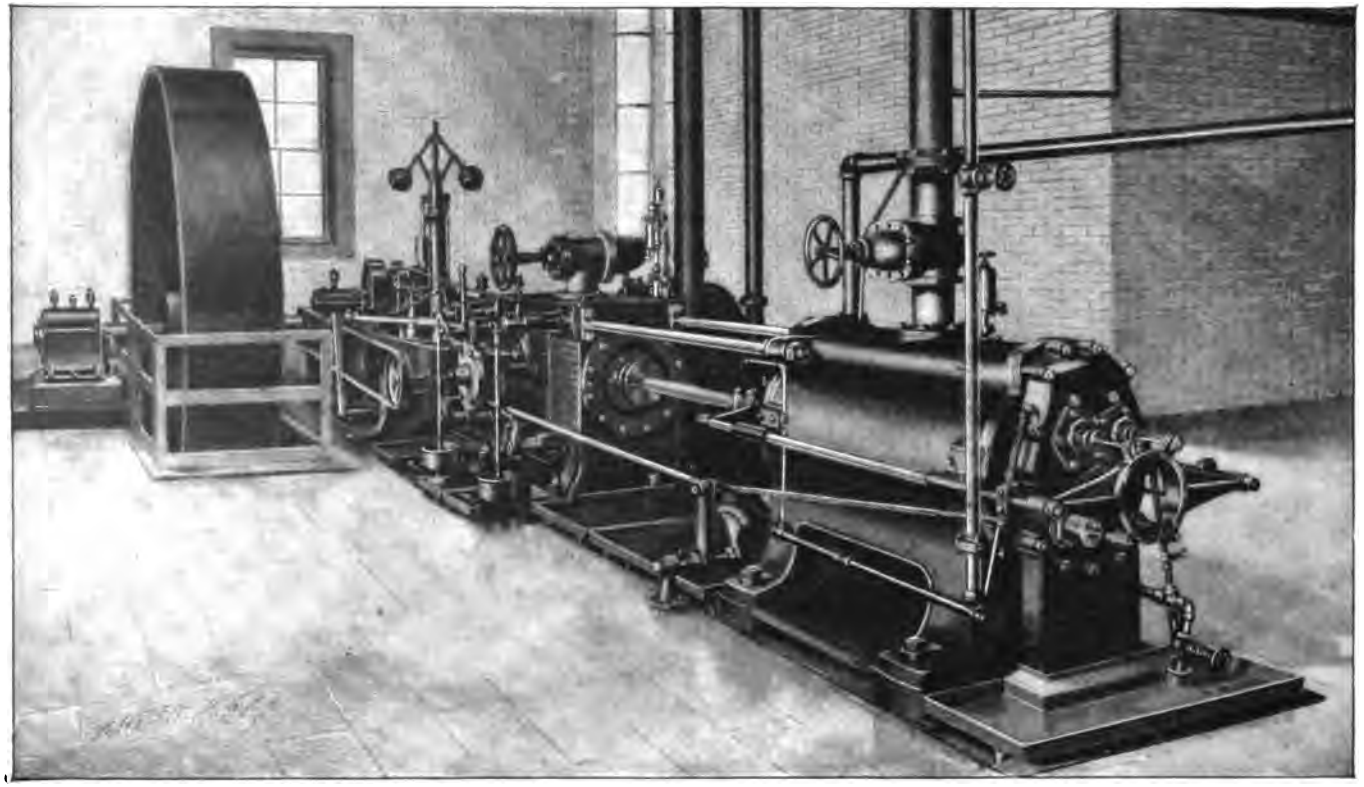


Fig. 3.

One great trouble with all these engines was that they required some one to open and close the cocks. Boys were generally employed to do this work. In order to get time to play, one of them rigged a catch at the end of a cord which was attached to the beam overhead. This did the work for him. Making the valves automatic in this way made it possible to dispense with the services of the boy and at the same time greatly increase the speed of the engine. This engine was improved slightly from time to time by different inventors and was very extensively used until



RAND-CORLISS AIR COMPRESSOR

Watt's time. Some of them are in existence today. While this engine was a success and a great improvement over its predecessors, it was still very large, wasteful and heavy, in comparison with the work done. When the cylinders were made of iron they were simply cast and not bored, thus leaving a rough, stony coating over the iron, called the skin.

In the year 1763, a small model of a Newcomen engine was taken to the shop of an instrument maker in Glasgow, Scotland, to be repaired. This instrument maker, whose name was James Watt, had been studying steam engines for some time and he became very much interested in this model. He was a man of great genius, and before he died his inventions had made the steam engine so perfect a machine that there has been but one really great improvement in it since his time; namely, compound expansion. All other improvements have been merely following in the line of his suggestions and constructing what he could not for lack of good tools.

He found that to obtain the best results it was necessary, "*First, that the temperature of the cylinder should always be the same as that of the steam which entered it; and, secondly, that when the steam was condensed it should be cooled to as low a temperature as possible.*" All improvements in steam-engine efficiency have been in the direction of a more complete realization of these two conditions.

In order to keep the cylinder nearly as hot as the entering steam, Watt no longer injected water into the cylinder to condense the steam, but used a separate vessel or condenser. He made his piston tight by using greater care in construction, so that it was not necessary to have a water seal at the top. He then covered the top of the cylinder to prevent air from cooling the piston. When this was done he could use steam above as well as below the piston; this made the engine double acting.

Also, in the effort to keep the cylinder as hot as the entering steam, he enclosed the cylinder in a larger one and filled the space between with steam. This was not often done, however, and only of late years has the steam jacket been of much advantage. He also used steam expansively, that is, the admission of steam was stopped when the piston had made a part of the stroke; the rest

of the stroke was completed by the expansion of the steam already admitted. This plan is now used in all engines that are built for economy.

Other inventions made by Watt on his steam engine were: a parallel motion, that is, an arrangement of links connecting the

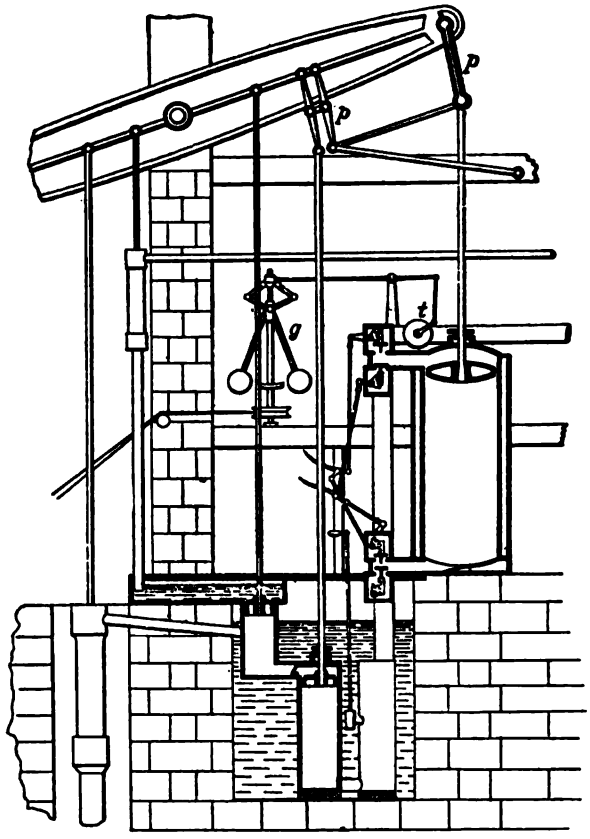


Fig. 4.

end of the piston rod with the beam of the engine in such a way as to guide the rod almost exactly in a straight line; the throttle valve, for regulating the rate of admission of steam and the centrifugal governor, which controlled the speed by acting on the throttle valve.

Watt also invented the "indicator," by means of which diagrams are made which show at all points the relation between the

pressure in the cylinder and the position of the piston at that instant. His assistant, Murdoch, invented the slide valve as a means of admitting and releasing the steam. Fig. 4 shows Watt's final engine.

Watt, like other early inventors, sold many of his engines to miners, who had been using horses to pump out the mines, and for this reason he rated his engines by the horse-power. Although this term has an historical derivation it has no real significance, and no relation whatever to the power of a horse. It is an established unit for measuring the rate at which work is done. One horse-power is the amount of work necessary to raise 33,000 pounds through one foot in one minute; and we may say that one horse-power is equal to 33,000 foot pounds per minute.

Watt saw that by using high-pressure steam he could get more work from it; but as it was not possible to make very reliable boilers he never used a pressure of more than seven pounds per square inch above the atmosphere. About the year 1800 comparatively high pressures came more into use and the *non-condensing* engine was introduced. In Watt's engine, and all those preceding his, a vacuum was produced in front of the piston by condensing the steam, and either the atmosphere or steam at atmospheric pressure pushed it through the stroke. In the non-condensing engine, using high-pressure steam, the space in front of the piston could be opened to the atmosphere at exhaust, and although the atmospheric pressure resisted its motion the pressure of the steam behind the piston was still greater than that of the air. These engines were much more simple than the condensing engines, as they required no condenser.

About this time what would now be called a compound engine was introduced by Hornblower and later by Woolf. It had two cylinders of different size. Steam was admitted into the smaller cylinder, and then passed over into the larger. The steam expanded a little in the smaller cylinder and much more in the larger one.

A great many attempts were made to build *locomotives*, but they were generally unsuccessful until George Stephenson built his engine, the "Rocket," in 1829. The principal new feature of this engine was the improved *steam blast* for increasing the

draft in the furnace and so making possible the use of a smaller boiler. Later he used the "link motion," which enabled the engine to be quickly reversed and the amount of expansion varied.

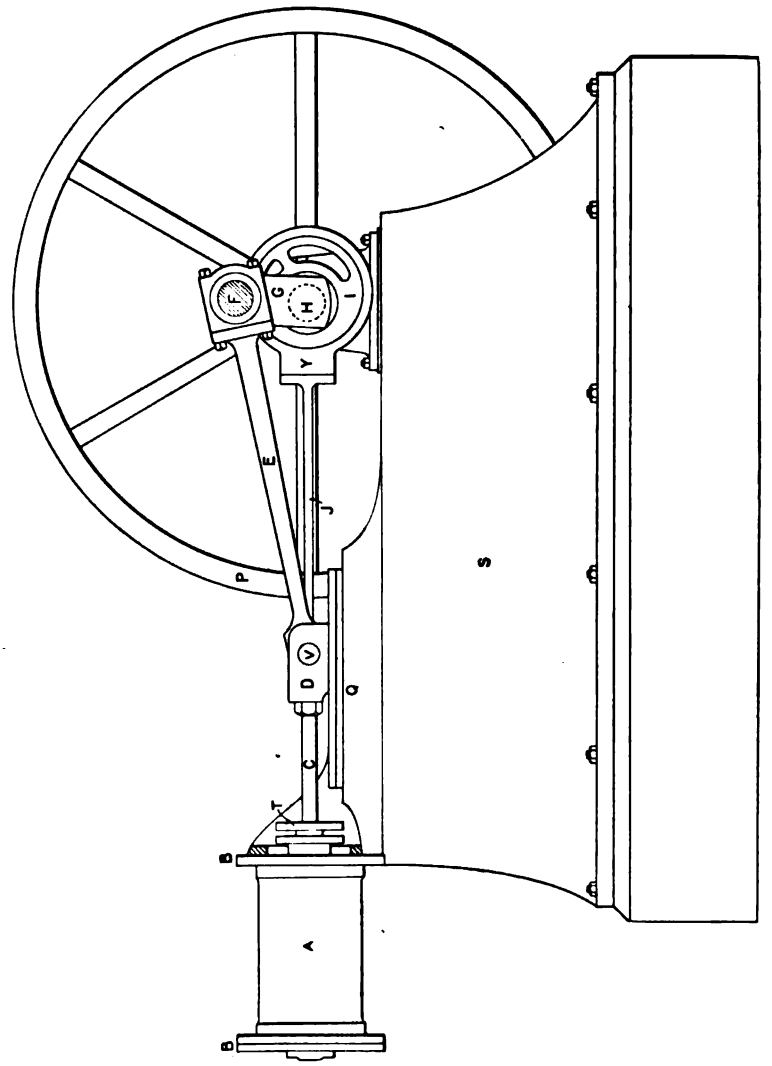
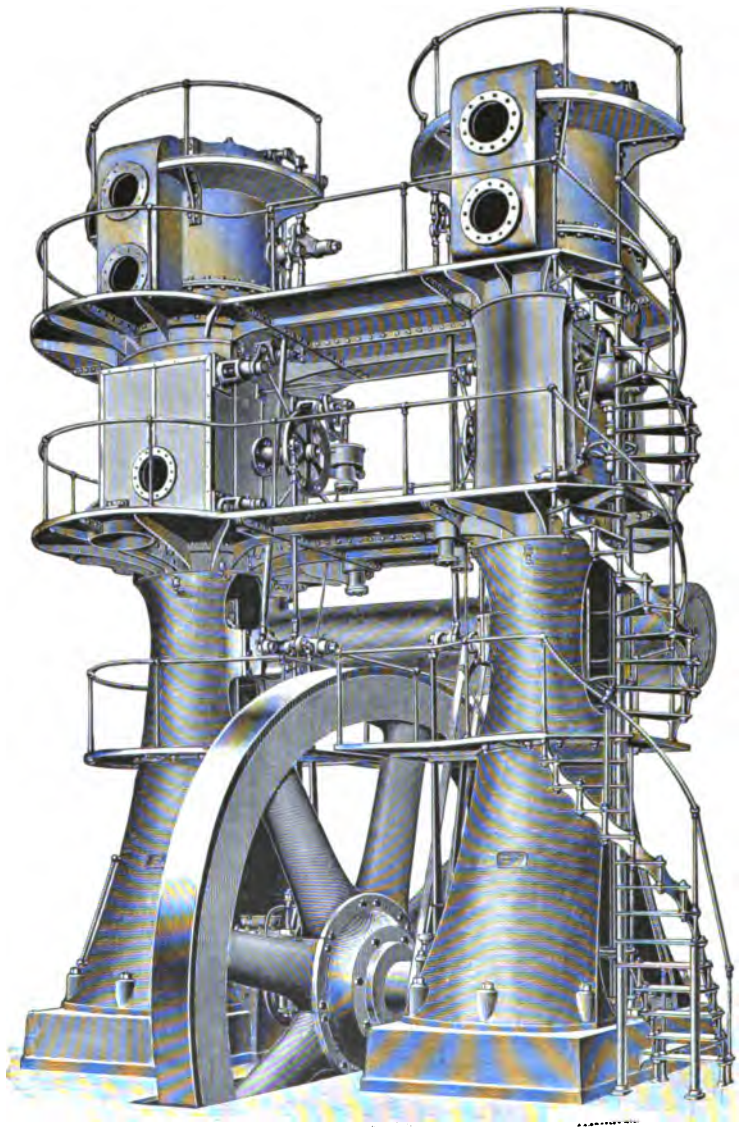


Fig. 5.

The Stephenson link motion may be seen on almost any locomotive. It is simply a device by which either of two eccentrics may be made to move the valve.

About the year 1814, Woolf introduced a compound pump-



VERTICAL COMPOUND BLOWING ENGINE
ALLIS-CHALMERS COMPANY

ing engine in the mines of Cornwall, but a simpler engine was later introduced and Woolf's engine fell into disuse. This later engine became known as the Cornish Pumping Engine and was famous for many years because of its economy. It was the first engine ever built that could compare at all with modern engines in the matter of steam consumption. It consisted of a single cylinder placed under one end of a beam from the other end of which hung a heavy rod which operated a pump at the foot of the shaft. Steam was admitted on the upper side of the piston for a short portion of the stroke and allowed to expand for the remainder of the stroke. This forced the piston down, lifted the heavy pump rod and filled the pumps with water. Then communication was established between the upper and under side of the piston, exhaust occurred, and the heavy pump rod fell, lifting the piston and forcing the water out of the pumps. The cut-off was about .3 stroke, and the pump made about seven or eight complete strokes per minute with a short pause at the end of each stroke to allow the valves to close easily and the pumps to fill with water. The cylinder was jacketed. These engines needed great care and were in charge of competent men, to whom prizes were frequently given for the best efficiency, which doubtless accounts for their wonderful performance.

PARTS OF THE STEAM ENGINE.

Fig. 5 shows the elevation of a simple form of steam engine.

The Cylinder A (see plan, Fig. 6) is that part of the engine in which the piston moves back and forth. It is made of cast iron and accurately bored. Great care must be taken in this work, for any unevenness will allow steam to leak through between the piston and cylinder walls or it may even cause the piston to stick or work hard. In large engines the cylinder consists of two parts, the outer or cylinder proper and a comparatively thin cast iron liner. A space can be left between them for a steam jacket. Should the cylinder liner be damaged, it can be replaced without the expense of a new cylinder.

The Cylinder Heads B cover the ends of the cylinder and are securely bolted thereto. In the crank-end cover there is an opening for the piston rod to pass through. This opening is made

steam tight by a stuffing box which surrounds the piston rod. Sometimes the piston rod is prolonged beyond the piston and through the front cover. This extension of the piston rod is to

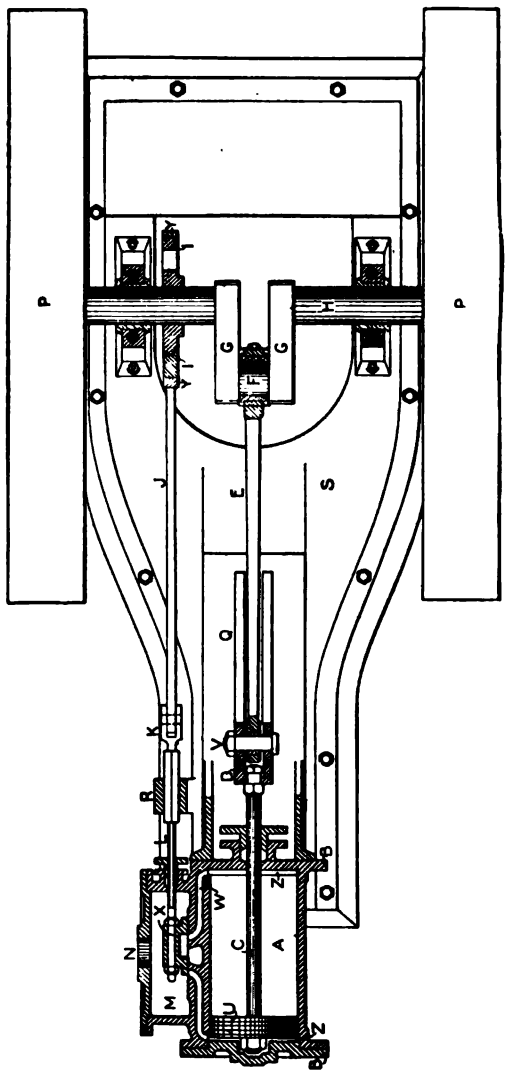


Fig. 6.

help steady the piston in a long stroke and is known as the tail rod. When a tail rod is used another stuffing box must also be provided for the head-end cover.

The Piston U, in small engines, is usually a thick disc of iron or steel, as shown in Fig. 6. It is often made conical, as shown in Fig. 7, to better withstand the steam pressure and to gain space. The piston must fit the cylinder steam tight and yet move easily. To accomplish this, one or more grooves in the piston are filled with packing (usually metallic), or spring rings may be used.

The Piston Rod C (Figs. 5 and 6) is made of steel and connects the crosshead and the piston to which it is rigidly fixed.

The Crosshead D serves to join the piston rod and connecting rod. At one end it is fastened to the piston rod, and at the other end is the wrist pin V on which the connecting rod swings. It is guided to and fro by the crosshead guides Q.

The Connecting Rod E is a steel forging from three to eight times the length of the crank, depending upon the type of engine. One end is jointed to the crosshead by the pin V, called the wrist pin, while the other encircles the crank pin and revolves with it. A detail view of one end is shown in Fig. 8; the other end is frequently similar. In some cases the small end is forked, as shown in Fig. 9.

The Crank Pin F forms the connection between the crank and connecting rod.

The Crank G, equal in length to one-half the stroke of the piston, converts the back and forth motion of the connecting rod into circular motion. It may be simply an arm, as shown in Fig. 10, or a complete disc keyed to one end of the shaft, as shown in Fig. 11. The disc is more nearly balanced than the crank.

The Shaft H transmits the rotary motion from the crank to the fly wheel P.

The Frame of the engine S is a heavy casting, which supports the cylinder and bearings. It should be securely bolted to the foundation.

The Steam Chest M receives steam directly from the boiler, and the steam passes thence through the ports W into the cylinder.

The Eccentric I is a disc keyed to the shaft so that its center and the center of the shaft do not coincide. The eccentric strap Y encircles the eccentric and imparts a reciprocating motion to the valve stem L and the eccentric rod J. This action is similar to

that of the crank and connecting rod, but exactly reversed. K is the valve stem crosshead and R its guides.

The Slide Valve X is the valve for alternately admitting

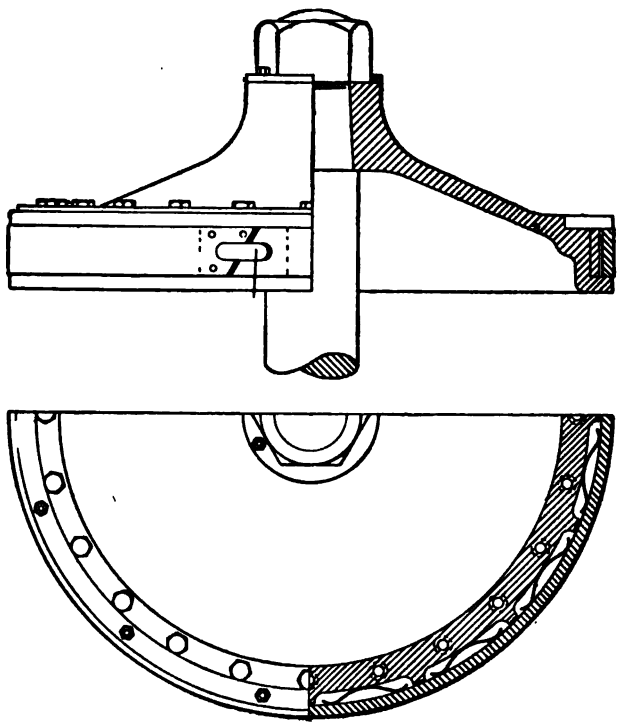


Fig. 7.

steam to the cylinder and releasing it. It has a cup-shaped cavity in its face through which the exhaust steam passes. It is situated in the steam chest and is moved by the valve gear, that is, the eccentric and the eccentric rod.

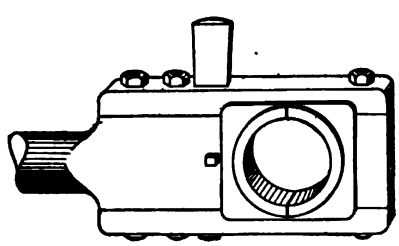


Fig. 8.

The Clearance Z is the space between the piston and the cylinder head (when the piston is at the end of the stroke), together with the volume of the steam ports. This volume must be filled with steam before the piston can start. It is usual to

express the clearance as a certain per cent of the volume swept through by the piston.

The crank may revolve in either direction. If we stand by the cylinder, facing the crank shaft, and the crank moves away from us as it passes over the shaft, we say that it is running *over*. If it moves away from us as it passes under the shaft, we say that the engine is running *under*. The action of steam in the

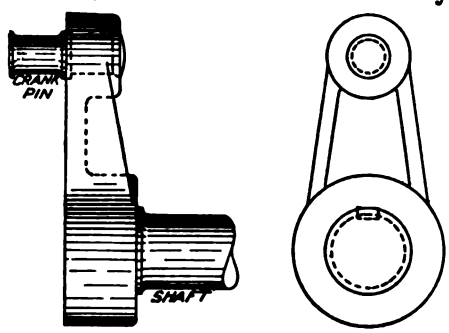


Fig. 10.

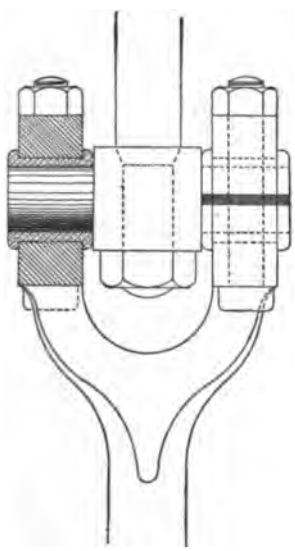


Fig. 9.

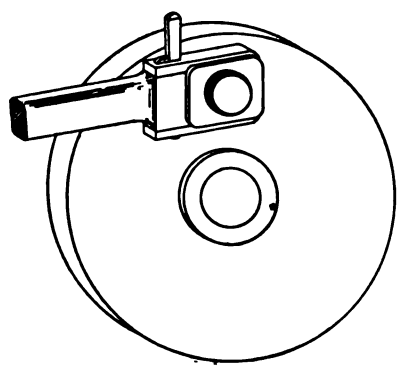


Fig. 11.

cylinder of an engine is very complicated, and its discussion will be taken up later in the course.

TYPES OF ENGINES.

Classification. There are so many different types of engines that it is difficult to classify them all properly. Most engines belong to several classes at one and the same time. For instance, there are condensing and non-condensing engines; there are

simple, compound, triple and quadruple expansion; there are high speed and low speed, vertical and horizontal, locomotive, stationary

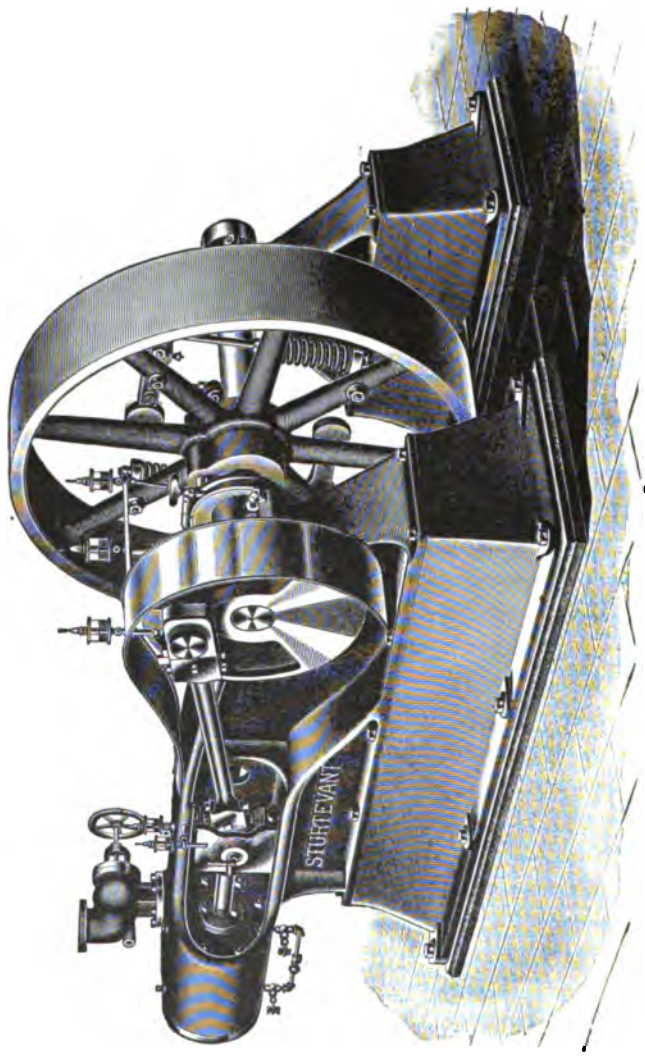


Fig. 12.

and marine, and many other classes into which these might be further subdivided.

Simple Engines. The simplest type of engine is the simple expansion. It has one cylinder and admits steam for a part of the stroke, expands it during the remainder and exhausts either into

the atmosphere or into a condenser. Simple engines (see Figs. 5 and 12) are now used only for comparatively small powers, say 100 H. P. or less, and although more extravagant of fuel than the others, may still be the most economical financially if low first cost is an important item, if they are not run continuously, or if the load fluctuates widely.

Compound Engines have two cylinders known as the high pressure and low pressure. Steam enters the smaller or high pressure cylinder and then expands until release, when it is exhausted into the larger cylinder, where the expansion is finished. The cylinders should be so proportioned that approximately the same amount of work can be done in each. The first cylinder is small, because it has the higher steam pressure, and a given weight of steam occupies less space when at high pressure. The second must be large, so that the volume at cut-off can contain all of the steam exhausted from the high.

Besides being more economical the compound has a distinct mechanical advantage. The two cranks may be set at right angles, so that when one is on dead center the other is at a position of nearly its greatest effort. This makes a dead center impossible, and gives a more uniform turning moment. Then the individual parts may be made lighter, and are thus more easily handled, but the engine is much more costly, and it is nearly twice as much work to take care of it.

When the cranks of a compound engine are at 90°, the low-pressure piston is not ready to receive steam when the high pressure exhausts, hence there must be a receiver to hold the steam until admission occurs in the low. Such engines are called *cross compound*. Fig. 13 shows one form. Sometimes instead of having the cranks at 90° they are placed together or opposite. Then the strokes begin and end together, and the high can exhaust directly into the low without a receiver. Such engines are called *Woolf engines*. A tandem compound engine, shown in Fig. 14, has both pistons on one rod, the high-pressure piston rod forming the low-pressure tail rod. Such engines are less expensive because there is but one set of reciprocating parts instead of two, but like simple engines they have the disadvantage of dead points.

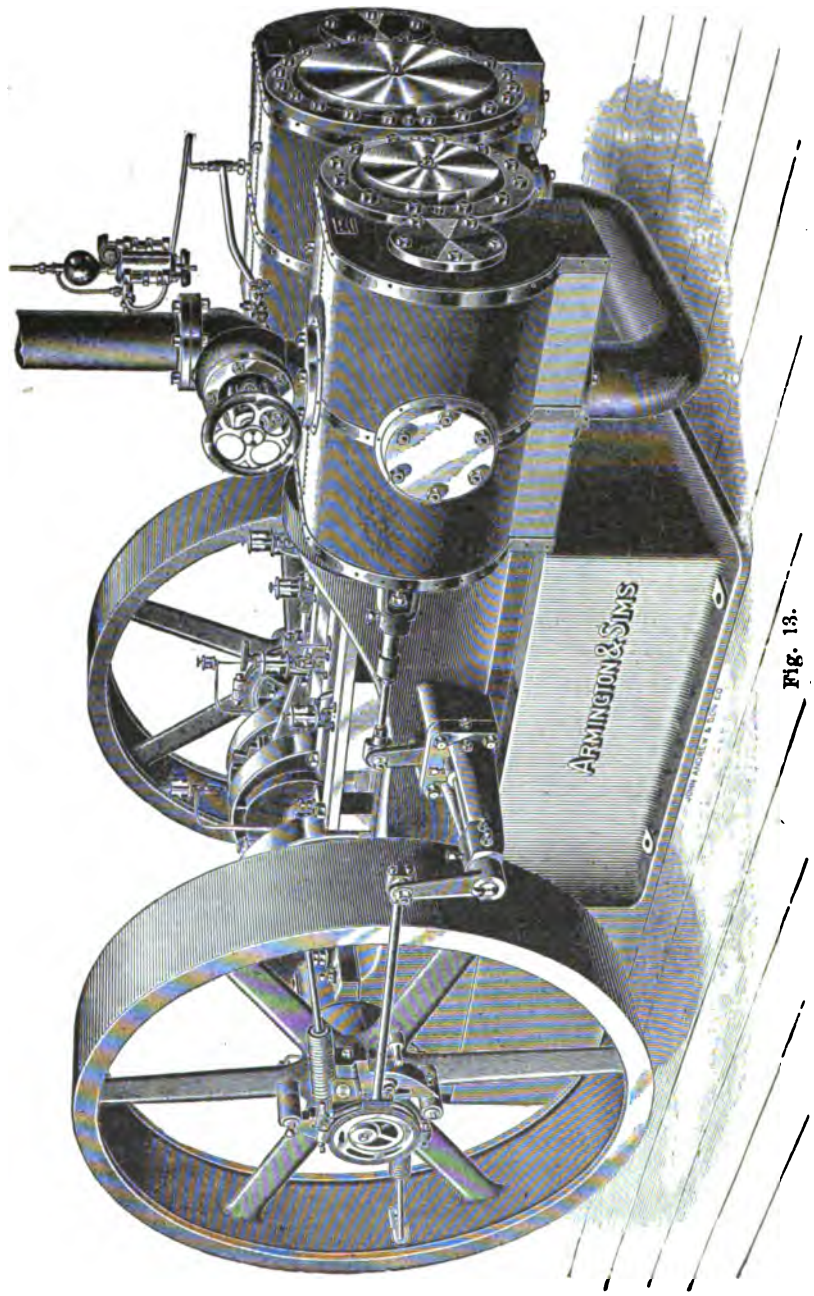


Fig. 13.

Triple Expansion Engines expand the steam in three stages instead of two. There are usually three cylinders, the high, intermediate, and low, arranged with cranks 120° apart. This gives a more uniform turning moment than a compound. Sometimes there are four cylinders to the triple, one high, one intermediate, and two low. This arrangement gives better balance and is often used in marine work.

For triple engines there must be a receiver between each two cylinders. Fig. 15 shows the essential features of a triple expansion engine.

Quadruple Engines expand their steam in four stages instead of three. Multiple-expansion engines are nearly always condensing.

Cylinder Ratios. There are several considerations to be remembered when proportioning the cylinders of multiple-expansion engines. The ratio of the cylinders should be such that each develops nearly the same power; the drop in pressure between the cylinders and receivers should be small, and the strains in the cylinders about equal.

There are many formulas in use, some simple, others involving mathematical calculation. A common rule for compound engines is to make the ratio of the cylinders equal to the square root of the total ratio of expansion. Thus if the steam has a ratio of expansion of 9, the ratio of the cylinder volumes will be $\sqrt{9} = 3$, or the low-pressure cylinder will have a volume 3 times as great as the high-pressure cylinder. If the cylinder ratio is 3, and the length of stroke is the same for both, the diameter of the low-pressure cylinder will be 1.75 times that of the high-pressure cylinder.

Another rule is to make the cylinder ratio equal to the total ratio of expansion multiplied by the fractional part of the stroke completed when cut-off occurs in the high-pressure cylinder.

Suppose the ratio of expansion is 9, as above, and that cut-off occurs at $\frac{1}{3}$ of the stroke in the high-pressure cylinder. The ratio of cylinder volumes will be $9 \times \frac{1}{3} = 3$. If cut-off occurs at $\frac{1}{2}$ the stroke, the ratio will be $9 \times \frac{1}{2} = 4.5$.

For triple expansion engines the low pressure cylinder is made large enough to develop the whole power if steam at boiler pressure is used.

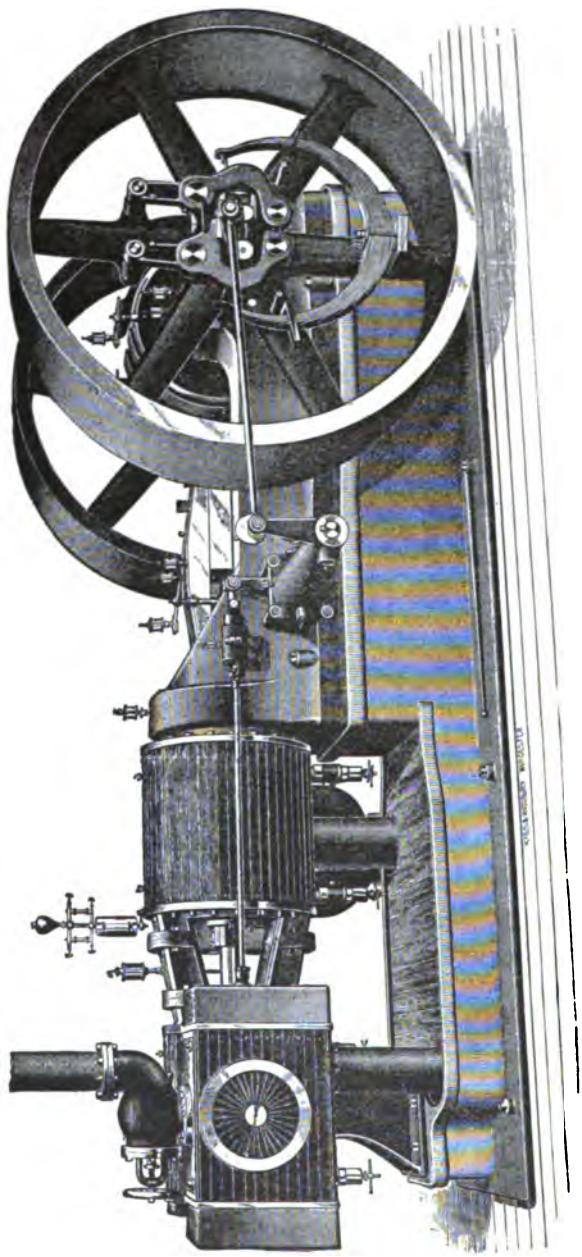


Fig. 14

The intermediate cylinder is made approximately of a mean size between the high and the low. The area of the intermediate piston is found by dividing the area of the low by 1.1 times the square root of the ratio of the low to the high.

We may write the above thus,

$$\text{Area of high-pres. cyl.} = \frac{\text{Area of low-pres. cyl.}}{\text{Cut-off of high-pres.} \times \text{ratio of exp.}}$$

$$\text{Area of inter. cyl.} = \frac{\text{Area of low-pressure cylinder.}}{1.1 \times \sqrt{\text{ratio of low to high.}}}$$

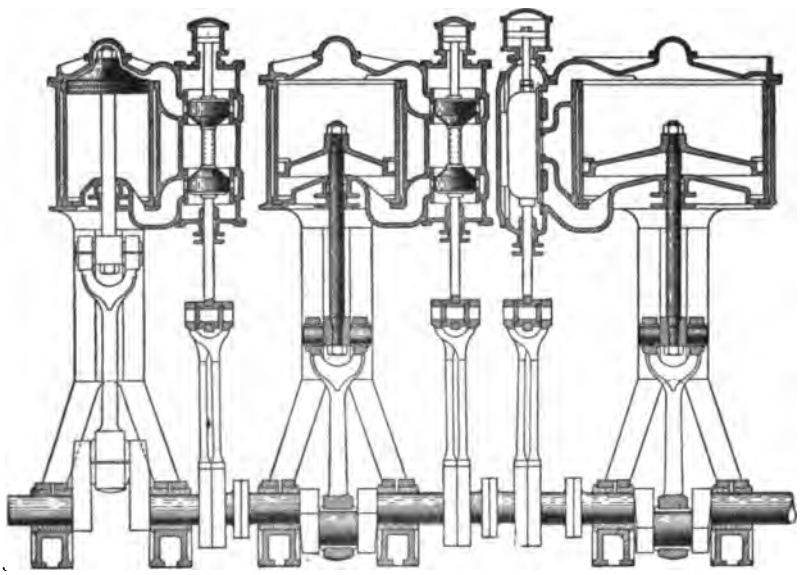


Fig. 15.

In general the volumes for triple expansion are of about the following ratios, 1 representing the volume of the high pressure cylinder:

1 : 2.25 to 2.75 : 5 to 8.

For quadruple-expansion engines the ratios are as follows:

1 : 2 to 2.33 : 4 to 5 : 7 to 12.

High Speed Engines. Of late years there has been a demand for engines of higher speeds than were formerly used. It was found desirable to run dynamo-electric machines by connecting them *directly* to the shaft of the engine rather than by belts as before.

This required engines running from 200 to 1,000 revolutions per minute instead of from 60 to 90 revolutions. Also for engines in

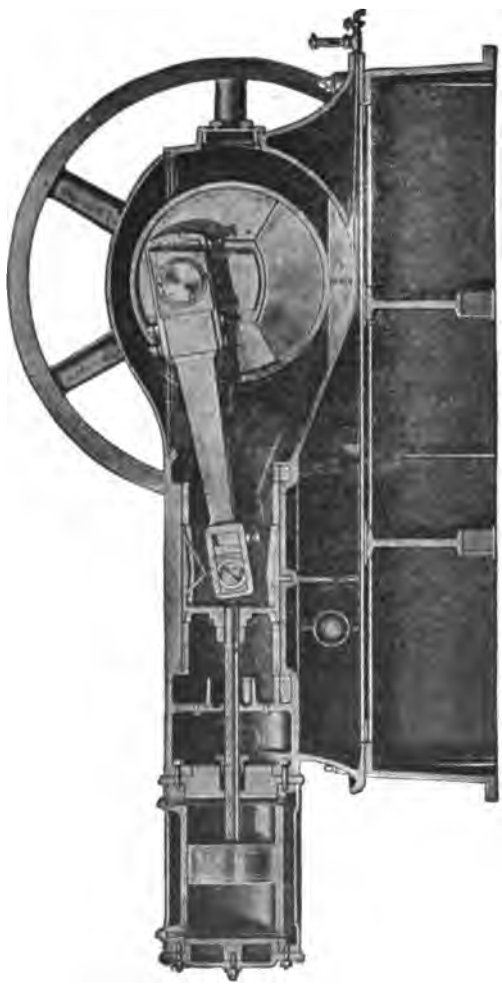


Fig. 16.

torpedo-boats, speeds as high as 400 or 500 revolutions are common.

Running at high speed requires various changes. Reciprocating parts must be made lighter to reduce the vibration, and must be

more carefully proportioned to maintain balance. Bearings must be made very much larger to reduce the pressure in order that the friction may not be excessive and cause heating. Special care is necessary that bearings should be tight, since the least looseness will cause knocking and hammering until the bearing is ruined. Parts must be as simple as possible and so arranged as to need the least possible attention. In slow-speed engines the engineer can watch the oil cups and oil any part while it is running. But this is impossible in high-speed engines, and special means must be used to insure plenty of oil to the bearings and the cylinder.

These peculiarities of high-speed engines may be easily seen in any engine for electric lighting, for running fans, etc. It is also necessary that the speed of engines for running electric generators should be very steady, as the slightest change in the speed make the lights flicker. The fly wheels are, therefore, larger or heavier than for other types and the governors are made specially sensitive. Fig. 16 shows a horizontal high-speed engine with the working parts encased. Fig. 17 shows a vertical high speed.

For any *double-acting* engine, that is, for any engine in which the steam acts first on one side and then on the other side of the piston, the piston first pushes and then pulls on the connecting rod and crank. At each half revolution of the crank the direction of the pressure reverses. It is this change of pressure which causes the pounding if the bearings are at all loose. This is one of the greatest troubles with high-speed engines. In order to avoid these rapid reversals in pressure, *single-acting* vertical engines are used to a considerable extent. In such engines the steam is admitted only to the *head end* of the cylinder. The other end stands open. The connecting rod is in compression throughout the whole revolution instead of being first in compression and then in tension. Besides insuring that the piston shall always push, this arrangement simplifies the valves.

There are several good single-acting, high-speed engines. One of the earliest made was introduced by Brotherhood. He used three cylinders, set around the shaft 120° apart. Another well-known example is the Willans "central valve" engine. These are both English engines. A well-known American engine

of this type is the Westinghouse high-speed engine, a section of which is shown in Fig. 18.

Vertical and Horizontal Engines. At the present time the most common type of engine is the horizontal direct-acting, that

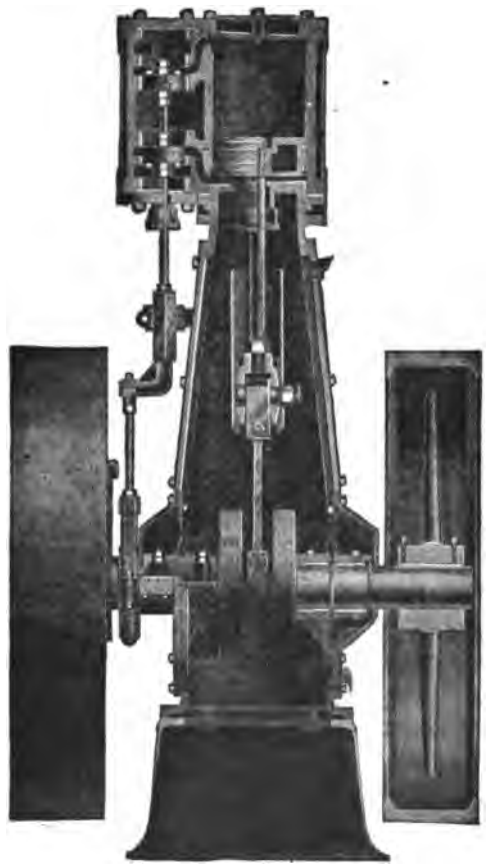


Fig. 17.

is, an engine whose cylinder is horizontal and whose piston acts on the crank through a piston rod and connecting rod. In small engines the whole is often on one bed plate. Such engines are called self contained. The cylinder is either bolted to the back of the bed plate or rests directly on it.

In marine work vertical engines are used in almost every case. The reason for this is, of course, the saving of floor space, which is so important in a vessel. This saving of space, however, is also

very important in many cases such as in crowded engine rooms of cities where land is expensive, and as there are a number of advantages which vertical engines have over horizontal, they are coming largely into use in stationary practice.

A second advantage of the vertical over the horizontal engine is the reduction of cylinder friction and unequal wear in the cylinder of the latter. In the horizontal engine the piston is generally supported by resting on the cylinder, which is gradually worn until it is no longer round. This causes leakage of steam from one side to the other. Evidently this is entirely avoided in the vertical engine.

Still another advantage of the vertical engine is the greater ease of balancing the moving parts so that there shall be no jarring or shaking. It is impossible to perfectly balance a steam engine of one or two cylinders. If it is balanced so that there is no tendency to shake sidewise, it will shake endwise; and if it is balanced endwise it will shake sidewise. The jarring is due to the back and forth motion of the reciprocating parts and the centrifugal force of the crank and connecting rod. The crank can be readily balanced by making it extend as far on one side of the shaft as it does on the other, but the piston and connecting rod are more difficult to balance. We can greatly reduce the effect of jarring if we balance the crank and make the endwise throw come in line with the foundation, which should be heavy enough to absorb the vibration transmitted. In a horizontal engine this endwise throw not being in line with the foundation will cause vibration in the engine itself.

In machines that can be anchored down to a massive foundation a state of defective balance only results in straining the parts and causing needless wear and friction at the crank-shaft bearings and elsewhere, and in communicating some tremor to the ground. The problem of balancing is of much more consequence in locomotive and marine engines.

To sum up the general advantages of vertical engines: they have less cylinder wear, they take up less floor space, and they can be better balanced. In addition to these there are certain advantages which vertical engines have for certain kinds of work.

The disadvantages of vertical engines are as follows: The

pressure on the crank-pin is greater during the *down* stroke than during the *up* stroke because, during the down stroke the weight of the reciprocating parts is added to the steam pressure, and during the up stroke this weight is subtracted.

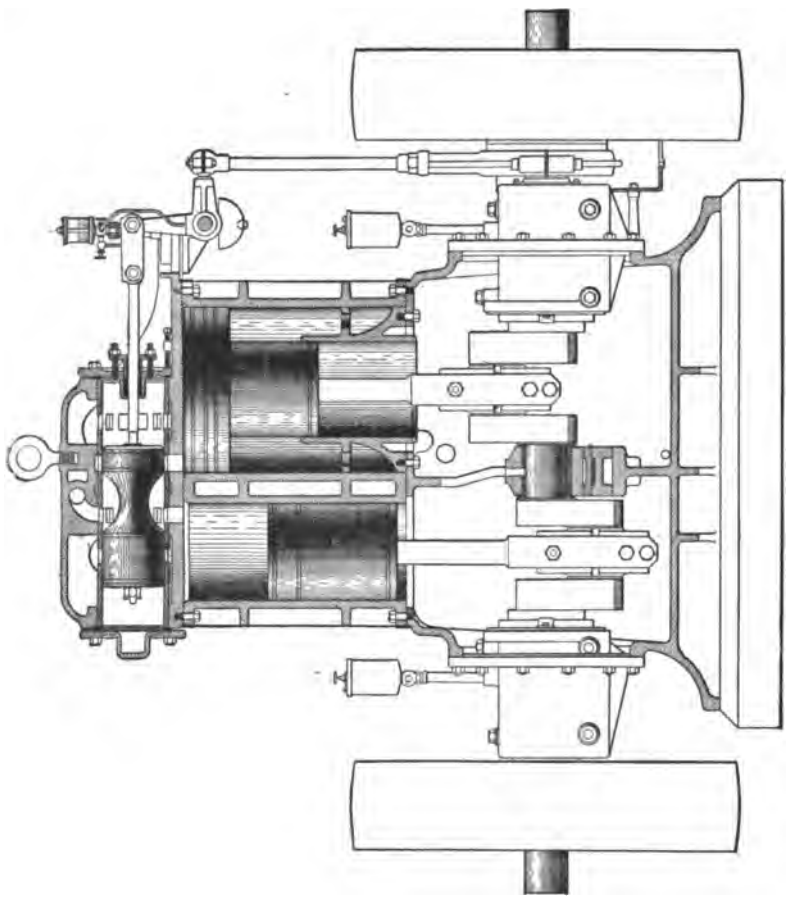
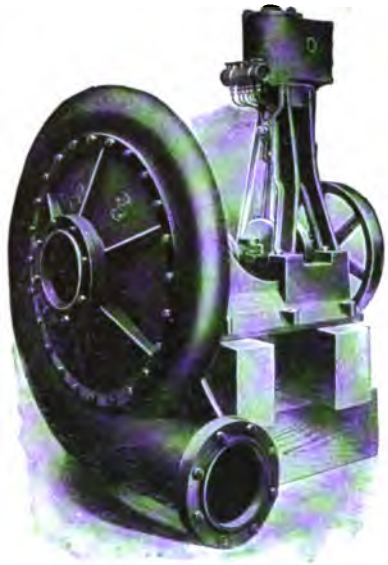
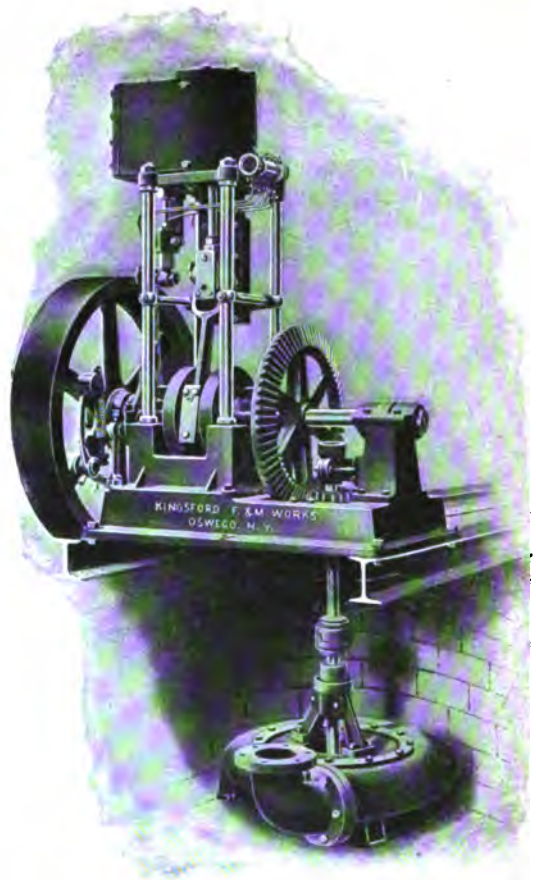


Fig. 18.

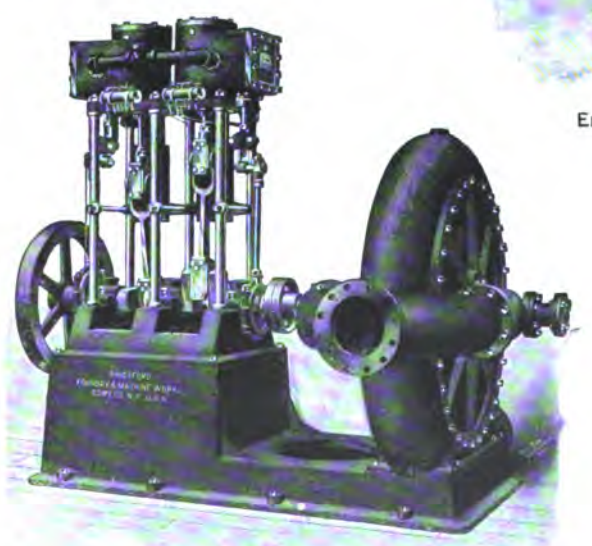
Another difficulty is that in large engines the various parts are on such different levels that they require considerable climbing. This requires more attendants and is sometimes the cause for neglect of the engine.



Side-Suction Pump
with Standard Engine.



Engine-Driven Vertical Pump.



15-inch Double-Suction Hydraulic Dredging Pump. (Special.)

The foundations for vertical engines generally need to be *deeper* than those for horizontal engines. At the same time, however, they need not be as *broad*.

Marine Engines. The first steam vessels were fitted with paddle-wheels, and as beam engines were the most common, this form of engine was used. Its construction, however, was somewhat modified for this service. This arrangement of beam engine and paddle-wheel was used for many years and was applied to ocean vessels as well as to small river boats. It is still used, especially in this country, on river steamers and some coast steamers. The beam is supported by large A frames on the deck, and the engines are about on a level with the shaft.

Engines of this type take up rather more room than those now in common use, partly because of great size, and also because of the shaft and paddle-wheels. Another disadvantage is that in heavy weather, when one paddle-wheel is thrown out of water the other is deeply immersed and takes all the strain, so that there is a tendency to rack the boat. Then again if the boat is loaded heavily the paddle-blades are very deeply immersed while if light they barely touch the water. It is hard to handle the engines satisfactorily under both conditions.

The introduction of the screw propeller overcame these difficulties very largely and at the same time required a much faster running engine. At first, the increased speed was supplied by the use of spur-wheel gearing, but gradually higher speed engines were built and connected directly to the propeller shaft. It was, of course, difficult with small width at each side of the shaft to use horizontal engines, therefore various arrangements of inclined engines were used before the vertical engine was finally chosen by all as the standard form for marine work. It is only in recent years that the vertical engine has become general in naval work and in merchant steamers.

In merchant ocean steamers the common form has three cylinders set in line, fore and aft, above the shaft. The cranks are 120° apart, to give a very even turning moment. The three cylinders are worked *triple expansion.* The valves are usually piston valves on the high and intermediate, and double ported slide valves on the low. Sometimes piston valves are used on all

the cylinders. Plain slide valves are not suitable for high-pressure work of any kind.

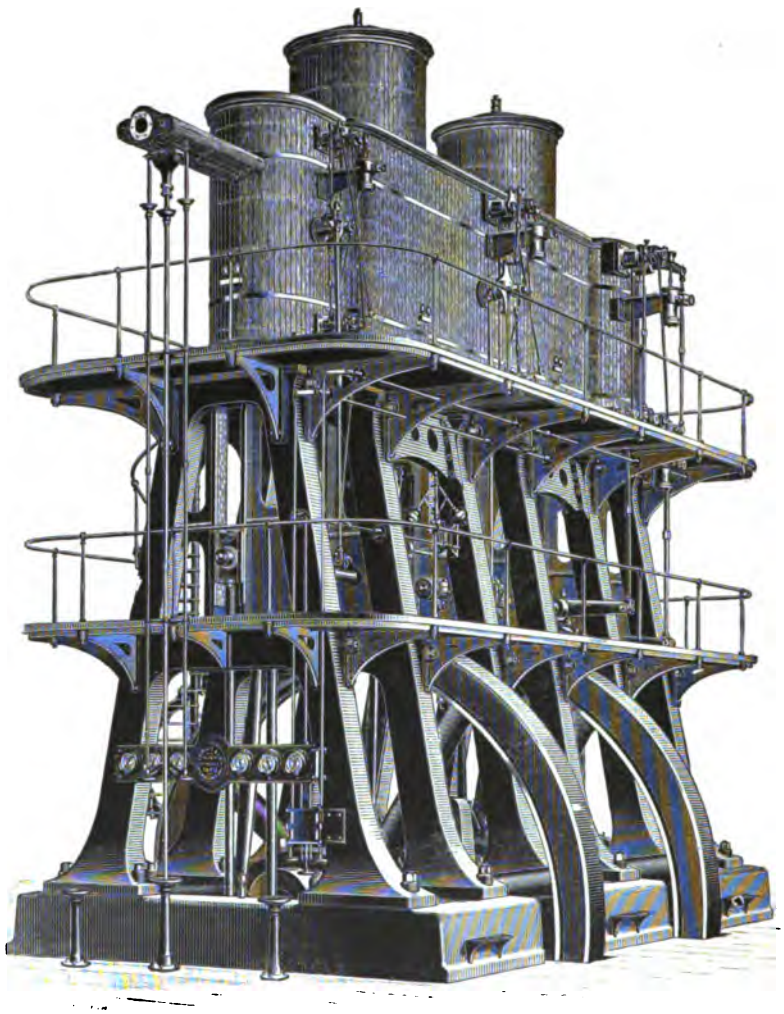
For engines on ocean vessels it is necessary to use surface condensers in order that the same water may be used over and over again. If it were necessary to take in sea-water for the boilers they would soon become clogged with the salt and require cleaning. Surface condensers for marine work are generally made up of a large number of brass tubes of from $\frac{3}{4}$ inch to 1 inch in diameter. In some cases the cold water is forced to flow through the tubes while the steam comes in contact with the outside of the tubes.

In any marine plant there are four special pumps. The *first* is the air pump for the condenser. This is usually made large so that in case there is a leak in the condenser it can take charge of the water even if it becomes necessary to run as a jet instead of a surface condenser. The *second* is the feed pump for the boilers. The *third* is the circulating pump, which forces the current of cold water through the condenser. The last is the bilge pump, which pumps out water that gathers in the bilge of the ship by leakage or otherwise. In case of a serious leak all the pumps can be made to pump from the bilges. In some old types all these pumps were worked from the main engine; generally, however, the feed pump and the circulating pump are separate, as also the bilge pump. The circulating pump is, in many modern engine rooms, of the centrifugal type.

Locomotive Engines. Of all steam engines the most inefficient is the steam locomotive. In the first place, the boiler must be forced so hard that the products of combustion pass off at a very high temperature and consequently carry away a great deal of heat. Bits of entirely unburned or partially burned coal are drawn through and wasted.

In the second place, the boiler is exposed to great loss of heat by radiation. Although its surface is lagged, it cannot be very effectively covered, and the wind takes away a great deal of heat.

Mechanically also the locomotive is very imperfect. In most good steam engines the efficiency, that is to say, the ratio of the *effective horse-power* to the *developed horse-power* is fully $\frac{9}{10}$ or 90 per cent. In the locomotive this ratio was shown to be about 43



VERTICAL TRIPLE EXPANSION PUMPING ENGINE
ALLIS-CHALMERS COMPANY

per cent by two independent tests. This is in part due to the special difficulties in locomotive construction, but the principal losses are those caused by radiation and the escape of heat from the stack.

As to locomotive boilers, Mr. Forney says, "The weight and dimensions of locomotive boilers are in nearly all cases determined by the limits of weight and space to which they are necessarily confined." It may be stated generally that within these limits a locomotive boiler cannot be made too large. In other words, boilers for locomotives should always be made as large as possible under the conditions that determine the weight and dimensions of the locomotives.

There are certain types of locomotives common in American practice which have special names. The eight-wheel or "American" passenger type of locomotive has four coupled driving-wheels and a four-wheeled truck in front. The "ten-wheel" type has six coupled drivers and a leading four-wheel truck. This type is used for both freight and passenger service. The "Mogul" type is used altogether for freight service; it has six coupled drivers and a two-wheel or pony truck in front. The "Consolidation" type is used for heavy freight service. It has eight coupled driving-wheels and a pony truck in front. There are also a great many special types for special purposes. In switch-yards a type of engine is used which has four or six drivers with no truck. The Forney type has four coupled driving-wheels under the engine and a four-wheel truck carrying the water-tank and fuel. This type is used on elevated roads largely. "Decapod" engines are a type used for heavy freight service, having ten coupled driving-wheels and a two-wheel truck in front. A tank engine is one which carries the feed water in tanks on the engine itself instead of in the tender, as in other engines. The various different forms are too numerous even to name.

There has been some effort made to introduce compounding in locomotive practice. It has in some cases been very successful, especially for express trains. A committee of the American Railway Master Mechanics Association says of compounding:

"(*a*) It has achieved a saving in the fuel burnt, averaging 18 per cent at reasonable boiler pressures.

(*b*) It has lessened the amount of water to be handle.

(*c*) The tender can, therefore, be reduced in size and weight.

(*d*) It has increased the possibilities of speed beyond sixty miles per hour, without unduly straining the engine.

(*e*) It has increased the haulage power at full speed.

(*f*) In some classes of engines it has increased the starting power.

(*g*) It has lessened the valve friction per horse-power developed."

A number of other reasons are given in their report.

In opposition to this may be mentioned the extra first cost of the engine and the cost of maintaining a more complicated machine. It is much more work to keep it in repair and many engineers are of the opinion that the saving in fuel is only sufficient to offset these extra expenses. If the engine is running under steady load, the compounding will effect a great saving; but in many parts of the country the load varies constantly, due to grades in the road.

We shall learn later that a compound engine cannot work efficiently under light load. If the grades are first up and then down, the simple engine is the more economical. For a steady up-grade the compound is more economical, as it can be run steadily under full load. This is especially true in mountain districts, where the long up-grades and scarcity of fuel and water make ideal conditions for compound locomotives. Through freight service probably offers the widest field for success with these engines.

It has already been said that it is difficult to balance an engine completely. This defect is very much greater in locomotives than in stationary engines. Lack of balance in a locomotive results in serious pounding of the track. Also there is danger of flattening and breaking the wheels, and the rails may be seriously damaged.

Pumping Engines. The first steam engines built were pumping engines and today the most economical engines are those built for this work.

In pumping engines it is not absolutely necessary to have a revolving shaft. All that is required is that the piston in the pump cylinder shall be driven back and forth with a plain recipro-

cating motion which may be exactly like that of the steam piston. For this reason, in early pumping engines and also in many modern engines, the reciprocating motion of the steam piston is applied directly, or through a beam, to produce the reciprocating motion of the pump piston or plunger without the use of any revolving part. Frequently, however, it is desirable to use a fly wheel so that the steam may be used expansively, and in these cases, of course, a revolving shaft must be used. Fig. 19 shows a power pump.

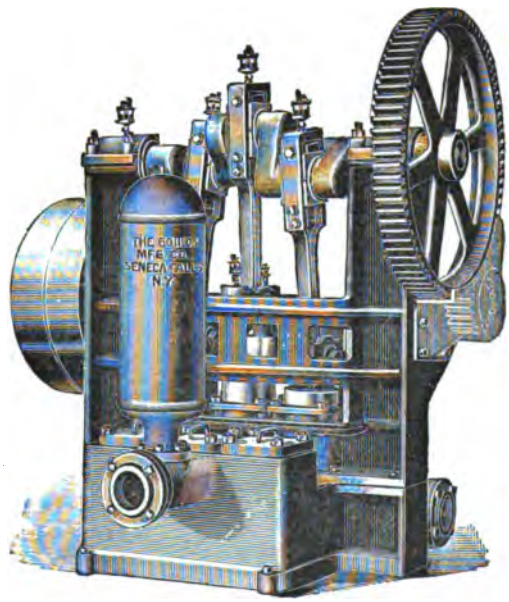


Fig 19.

For deep-well or mine pumping, the cylinders are often set in a vertical position directly over the pump cylinder. The piston rod extends from the steam cylinder directly below to the pump plunger. Sometimes it is possible to use steam expansively in these pumps by reason of the weight of the reciprocating parts. When the weight is sufficient, the steam can be cut off before the end of the stroke and the momentum of the parts will be enough to just finish the stroke, consequently these pumps are sometimes compounded. They are possible only in pumping from very deep wells.

Direct-acting Steam Pumps. Fly wheel pumps have one disadvantage, if run too slowly the momentum of the fly wheel is not sufficient to carry it by the dead centers; if run too fast the fly wheel is in danger of bursting. A fly-wheel pump can be made to discharge a small amount of water by means of a by-pass valve, but of course it then runs at a disadvantage.

The direct-acting steam pump shown in Fig. 20 has the steam piston at one end of a rod and the water piston at the other end. The steam pressure acts directly on the piston; no fly wheel is used, and since the reciprocating parts are comparatively light, and there is no revolving mass to carry by the dead points, it is evident that in the ordinary form there can be no expansion of steam. The pump is inexpensive and gives a positive action. It uses a great quantity of steam relatively, but for small work the absolute amount is not very great. Even in larger engines the lighter foundations that are possible and the slight first cost are frequently controlling features.

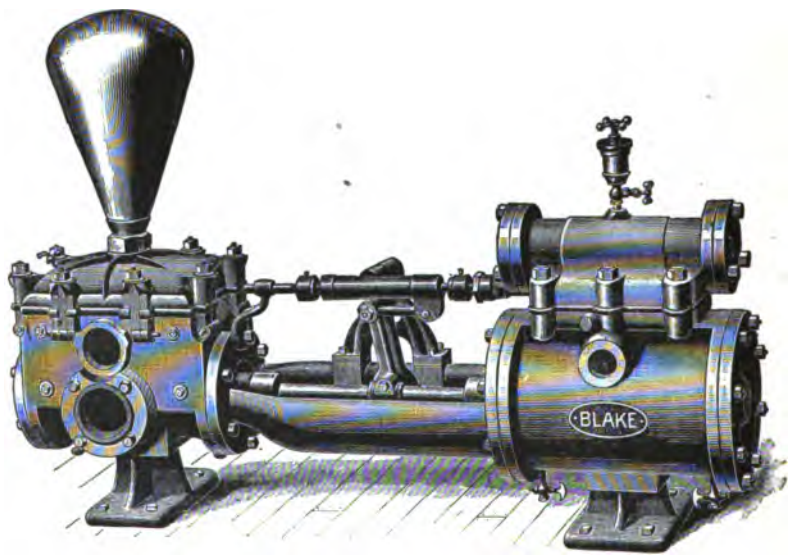
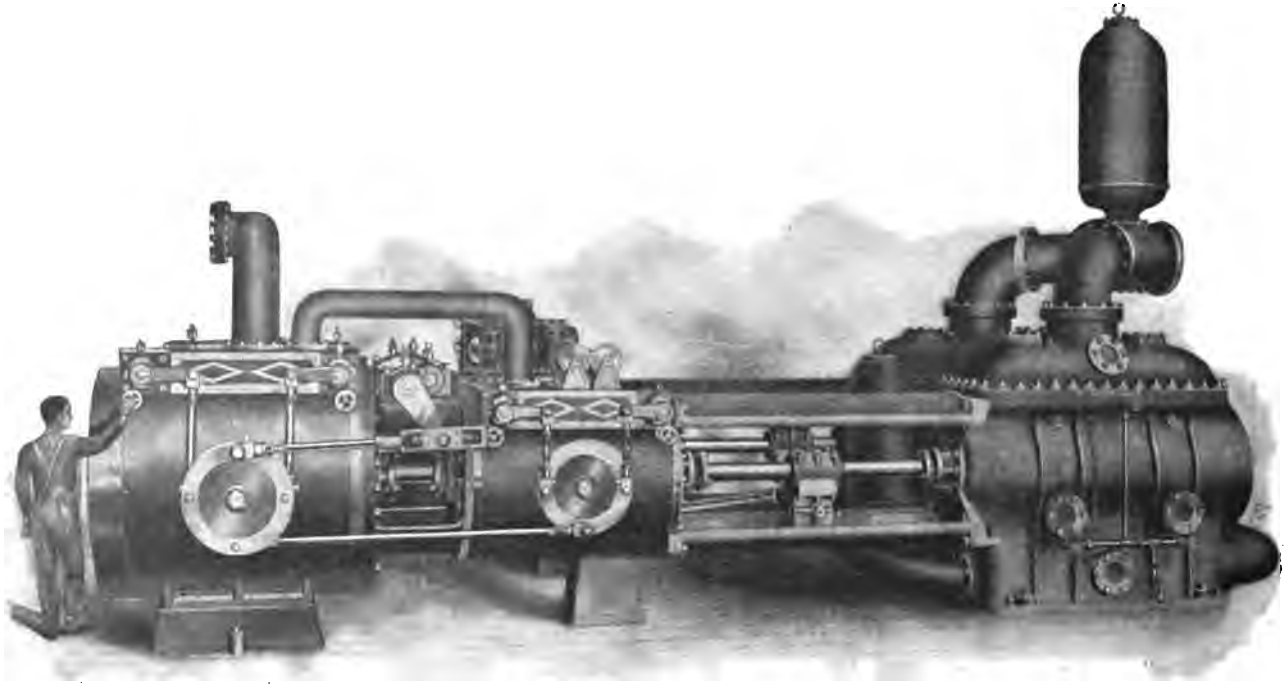


Fig. 20.

A rocker or bell-crank lever on the piston rod moves the steam valve and admits steam to the other side of the piston while opening the first side to exhaust. In large pumps of this kind, and even in some small ones, this motion merely admits steam to a small auxiliary piston which then moves the main steam valve by steam pressure. Some pumps operate the steam valve by means of a tappet instead of a rocker and bell-crank lever.

There have been various devices tried for using steam expansively in these direct-acting pumps without the use of a fly-wheel.



SMITH-VAILE COMPOUND PUMPING ENGINE—Capacity 5,000,000 Gallons 24 Hours

In order to do this it is necessary to provide some means of storing energy during the early part of the stroke and returning it during the latter part, when, owing to the expansion, the pressure of the steam is less. One such device is as follows: a crosshead A, (Fig. 21) fixed to the piston rod is connected to the plungers of a pair of oscillating cylinders B B, which contain water and communicate with a reservoir full of air compressed to about 300 pounds per square inch. When the stroke (which takes place in the direction of the arrow) begins, these plungers are first forced in, and hence work is at first done on the main piston rod, through the compensating cylinders B B, on the compressed air in the reservoir. This continues until the crosshead has advanced so that the oscillating cylinders stand at right angles to the line of stroke. Then for the remainder of the stroke their plungers

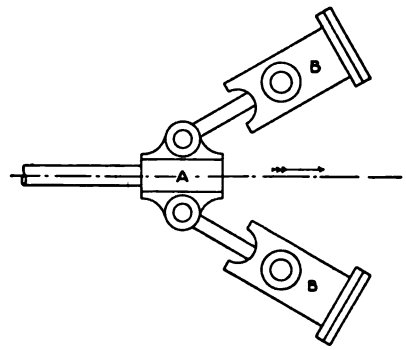


Fig. 21.

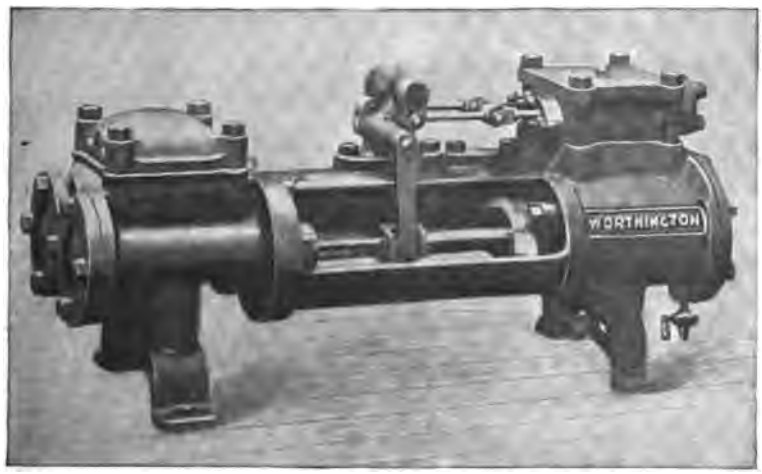


Fig. 22.

assist in driving the main piston, and the compressed air gives out the energy which it stored in the earlier portion.

The Duplex steam pump consists simply of two direct-acting steam pumps placed side by side, as shown in Fig. 22. On the piston rod on one side is a bell-crank lever which operates the valve of the other pump. On the further piston rod is a rocker arm which moves the valves of the first pump. There must be a rocker on one side and a bell-crank lever on the other because of the relative motion of the valves and pistons. The first piston, as it goes forward, must use a rocker because it draws the second valve back. The second piston, as it goes back, must use a bell-crank lever because it must push the first valve back in the same direction as its own motion. The two pistons are made to work a half-stroke apart. Thus one begins its stroke when the other is in the

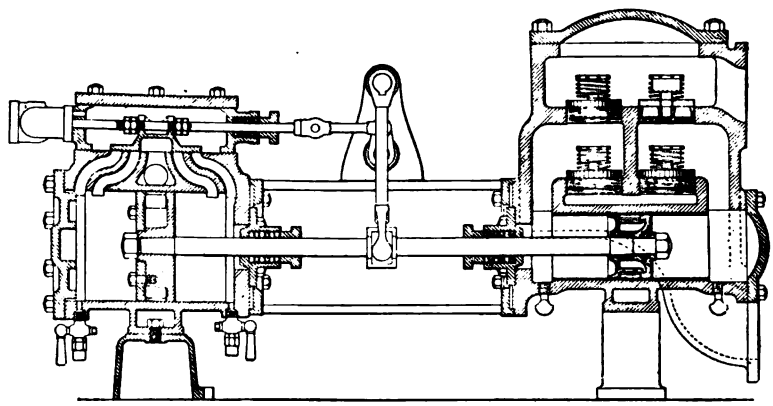


Fig. 23.

middle. In this way a steadier flow of water is obtained, for both pumps discharge into the same delivery pipe. The pumps may be made compound. A sectional view of the pump is shown in Fig. 23.

Corliss Engines. In large engines a common way of regulating the steam supply is by changing automatically the point in the stroke of the piston at which the steam is cut off. This is frequently accomplished by using some trip gear similar to the one first introduced by Geo. Corliss. These gears are called Corliss gears. In the Corliss gear there is a separate admission valve and a separate exhaust valve for each end of the cylinder, as shown in Fig. 24. The exhaust valves are opened and closed by

the motion of rods or cranks connected to them. The admission valves are opened in the same way, but they snap shut by themselves when the piston has reached a certain point of its stroke. This point will vary with the position of the governor, which in turn depends on the speed of the engine. These Corliss engines cannot be run at high speed because the trip gear requires some time to act.

The valves of Corliss engines turn in hollow cylindrical seats which extend across the cylinders. A wrist plate which turns on

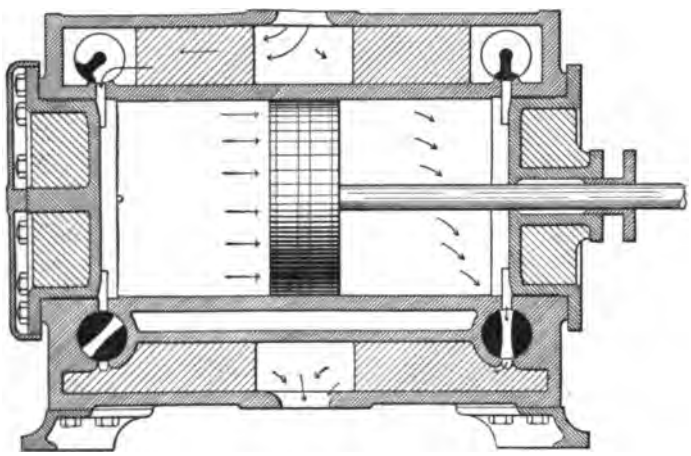


Fig. 24.

a pin on the outside of the cylinder receives a motion of oscillation from an eccentric and opens the valves by means of the rod connections. When the piston has reached a point where the steam should be cut off, the trip gear is held in such a position by the governor that it releases the valve, which now springs shut under the action of the dash-pot. The admission valve to the other side of the cylinder is controlled in exactly the same way.

The admission valves are generally placed at the top and the exhaust valves at the bottom of the cylinder. Any water which may be formed by steam condensing can readily drain off by this arrangement. There are a great many modifications of the Corliss gear. Fig. 25 is a Harris Corliss Engine.

The advantage of the Corliss gear is the great range through

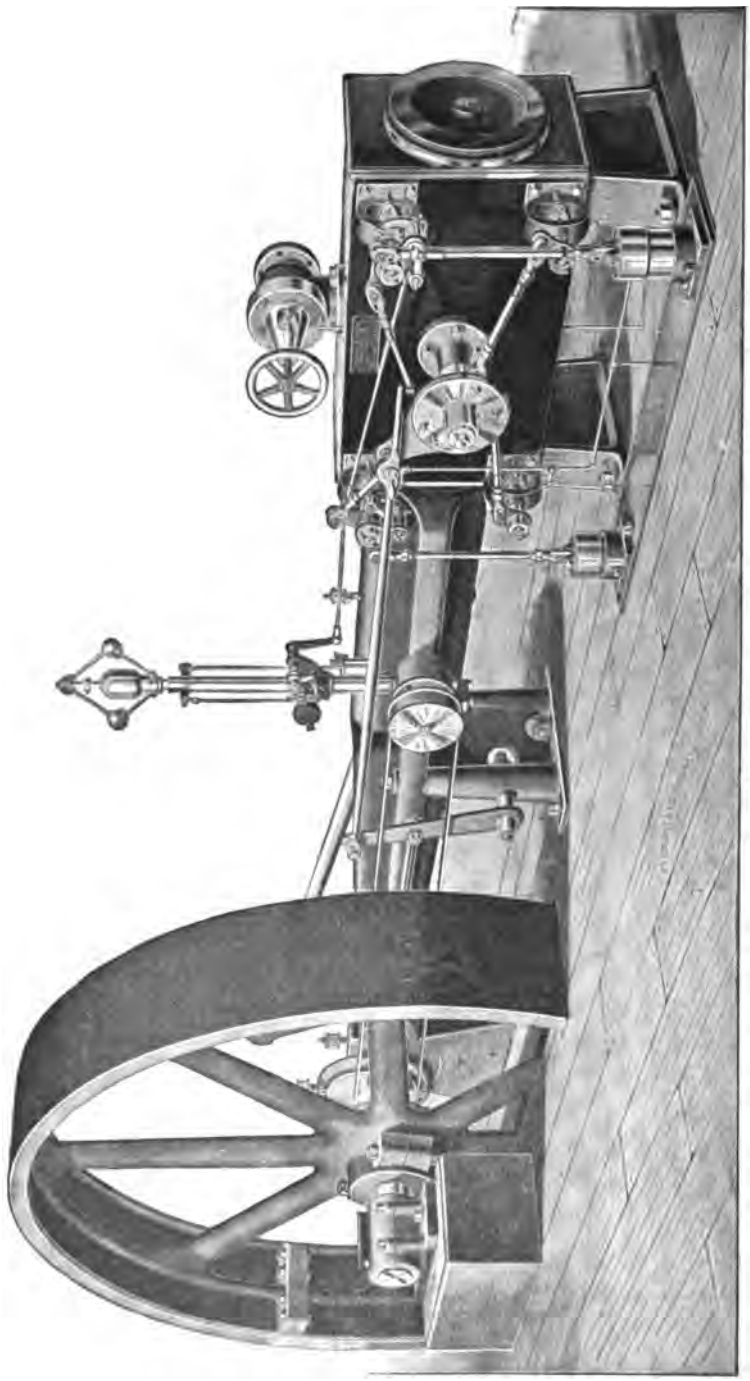


Fig. 25.

which the cut-off can be varied, from very early to very late in the stroke. Another great advantage is the quick action which reduces wire-drawing. To understand fully the loss caused by wire-drawing requires a knowledge of higher mathematics.

CONDENSERS.

When low-pressure steam is cooled it gives up its latent heat; that is, it changes from a vapor to a liquid. We know that a liquid occupies much less space than an equal weight of vapor; hence, by changing the steam to water the pressure is greatly reduced. By cooling the steam in the cylinder in front of the piston the back pressure, or resistance, is decreased. This reduces the pressure necessary to push the piston through the stroke, therefore less steam is required to do the work. This cooling is accomplished by some form of condenser.

There are two types of condensers, surface and jet. A surface condenser is one in which the steam passes through pipes surrounded by water or the water flows through pipes surrounded by steam. In the jet condenser the steam is condensed by coming in contact with cold water, which enters as spray. In both types the steam is condensed to water and a partial vacuum is formed, because water occupies much less space than does an equal weight of steam. If it were not for the air in the entering steam there would be an almost perfect vacuum. For this reason every condenser is fitted with an air pump to remove this air and the condensed steam.

Surface Condensers. The condenser shown in section in Fig. 26 is a common form of the surface type, in which the air pump and circulating pump are both direct acting and are operated by the same steam cylinder. The cold condensing water is drawn from the supply into the circulating or water pump. This pump forces the water up through the valves and water inlet to the condenser. It flows, as indicated by the arrows, through the inner tubes of the lower section, then back through the space between the inner and outer tubes. The water then passes upward and through the upper section, as it did in the lower. It then passes out of the condenser through the water outlet, taking with it the heat it has received from the steam.

The exhaust steam from the engine enters at the exhaust inlet and comes in contact with the perforated plate, which scatters it among the tubes. This method protects the upper tubing from the effect of direct contact with the exhaust steam. The steam expanding in the condenser comes in contact with the cool tubes,

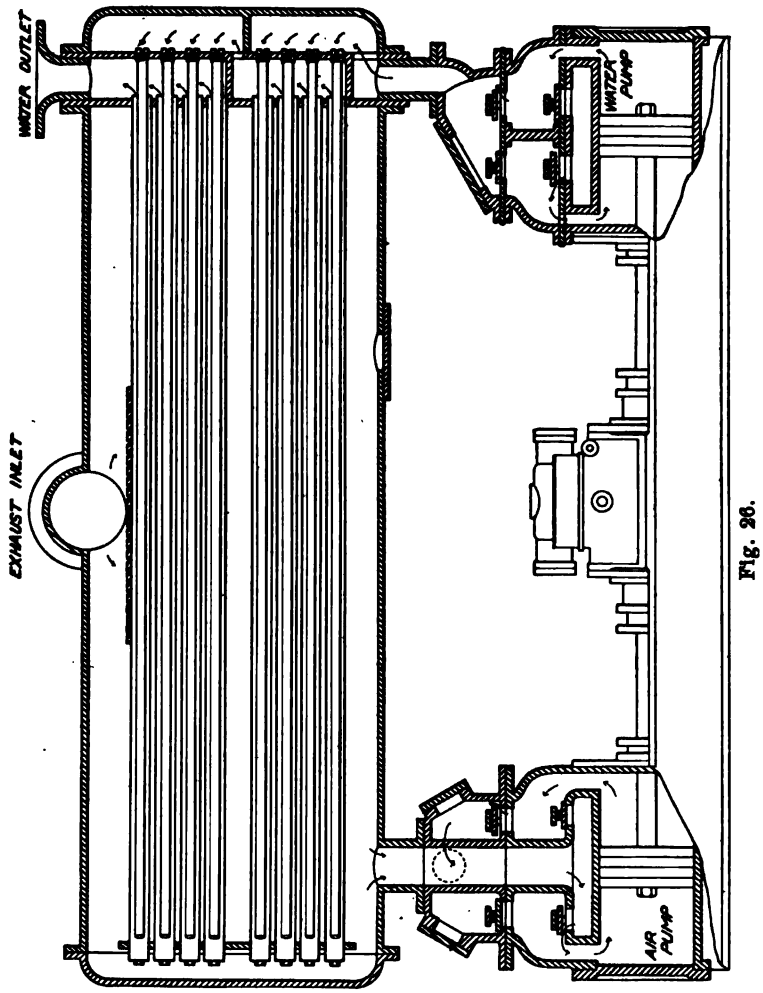
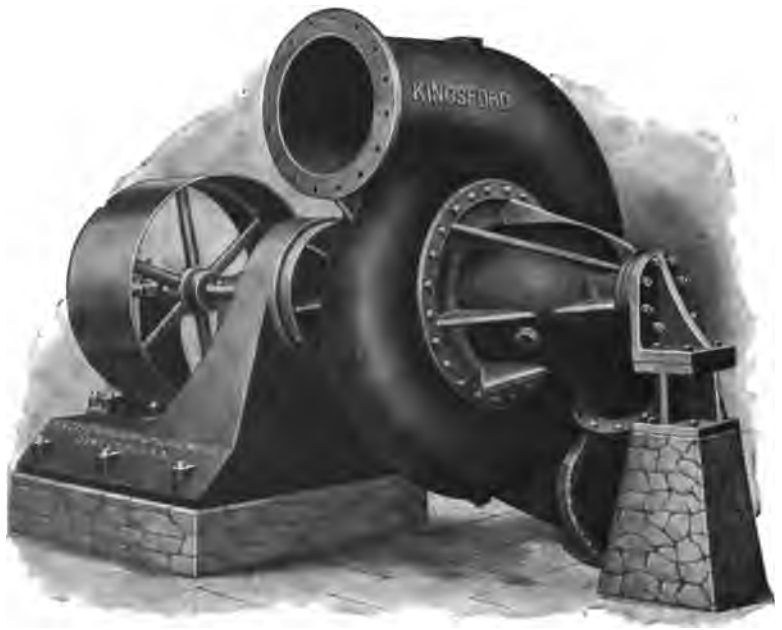
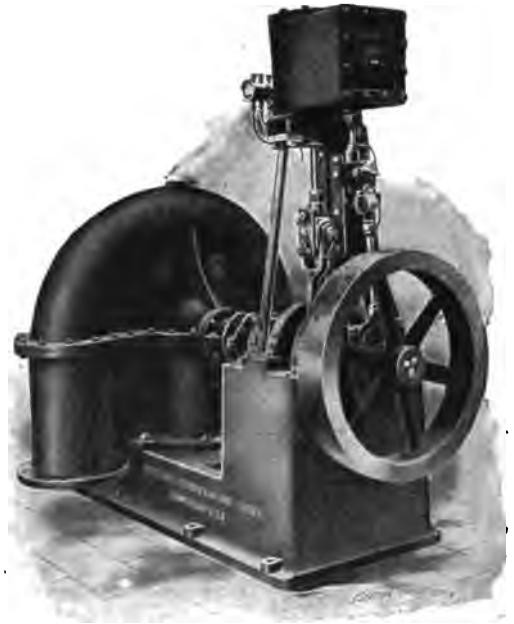


Fig. 26.

through which cold water is circulating, and condenses. The air pump draws the air and condensed steam out of the condenser and thus maintains a partial vacuum. This causes the exhaust steam in the engine cylinder to be drawn into the condenser.



Belt-Driven Pump on Masonry Foundation.



Direct Connected Steam-Driven Pump.

The condensed exhaust steam collects at the bottom of the condenser, is drawn into the air pump cylinder and is discharged while heated to the hot well of the boiler. The use of this hot water as feed water is a considerable saving; but the great advantage of the condenser is the reduction in back pressure.

Hot water cannot be used by an ordinary pump as well as cold water because of the pressure of the vapor which arises from the hot water. In the condenser shown, the water and air pumps are run by the piston in the steam cylinder. Sometimes these pumps are connected to the main engine and receive motion from the shaft or crosshead.

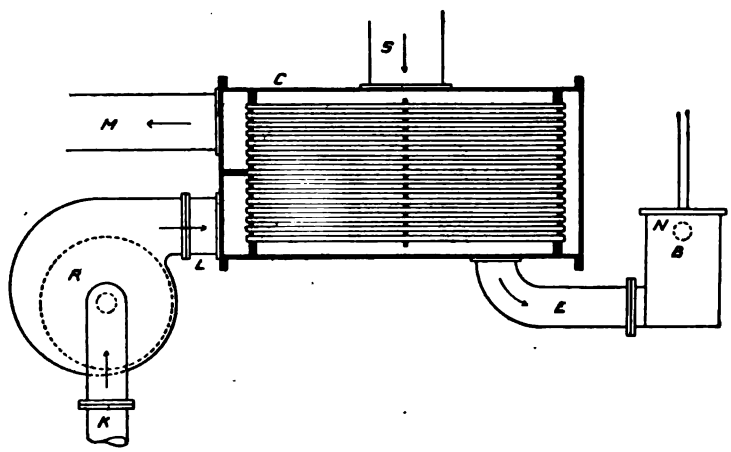


Fig. 27.

The general arrangement of the surface condenser with the necessary pumps is shown in Fig. 27. The cooling water enters through the pipe K, and flows to the circulating pump R, which forces the water into the condenser through the pipe L. In case the water enters the condenser under pressure from city mains no circulating pump is necessary. After flowing through the tubes it leaves the condenser by means of the exit M, and flows away. Exhaust steam enters at S, and is condensed by coming in contact with the cold tubes; the water (condensed steam) then falls to the bottom of the condenser and flows to the air pump B by the pipe E. The air pump removes the air, vapor and condensed steam from the condenser and forces it through the pipe N into the hot well, from which it goes to the boilers or to the feed tank

The circulating pump, when separate from the condenser, is usually of the centrifugal type. This pump consists of a fan or wheel which is made up of a central web or hub, and arms or vanes. This pump is shown in Fig. 28. The vanes are curved, and as the water is drawn in at the central part the vanes throw it off at the circumference. A suitable casing directs the flow. This type of pump is advantageous because there are no valves to get out of order, and as the lift is little, if any, the pump will discharge a large volume of water in a nearly constant stream. The circulating pump is usually so placed that the water flows to it under a slight head. The pump is driven by an independent engine so that the circulating water may cool the condenser even if the main engine is not working.

The centrifugal pump works more smoothly and with less trouble than an ordinary force pump, because it is not reciprocating and it has no valves.

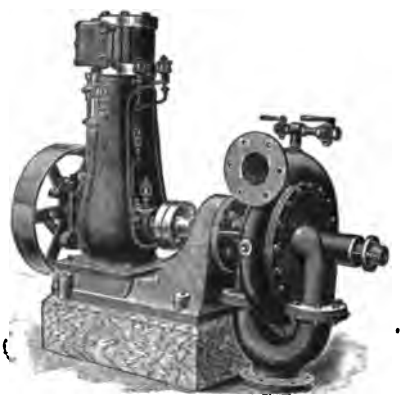


Fig. 28.

Jet Condensers. Fig. 29 shows the longitudinal section of an independent jet condenser with the pump. The cold water used to condense the steam enters at A, passes down the spray pipe B, and is broken into a fine spray by means of the spray cone C. This action insures a rapid and thorough mixing of the steam and water and consequently a rapid condensation. The exhaust steam enters at D, with a comparatively high velocity, which is imparted to the water. The whole mixture of water, steam and vapor passes at high velocity through the conical chamber E to the pump cylinder F. The pump forces this water to the pipe G. The spray cone is adjusted by the stem which passes through the stuffing box at the top of the condenser. The valves are shown at H and K. The steam end of the pump is at L. Motion of the valve is produced by the rocker arm J.

In Fig. 30 a jet condenser is shown connected to a stationary engine and boiler. The exhaust pipe leads from the engine to the

condenser, the arrows indicating the direction of flow. Cold water enters the condenser through a pipe connected to the well. Part of the mixture of exhaust steam and condensed water goes to the feed-water heater, which is kept nearly full; the rest passes to the sewer. The heater is placed a little above the feed pump, so that the water will enter the pump under a slight head, because the pump cannot raise water warmed by exhaust steam as readily as cold water.

The surface condenser is used almost universally in marine practice. Its first cost is more than that of the jet condenser and it requires more condensing water, but it allows only the condensed steam to return to the boiler. It is also used in stationary work when the condensing water is very impure. The jet condenser is not adapted for marine work, as it pumps both the condensing water and the condensed steam to the hot well. Hence, if salt water or water containing lime is used, it will enter the boiler and form sediment and scale. This type is used

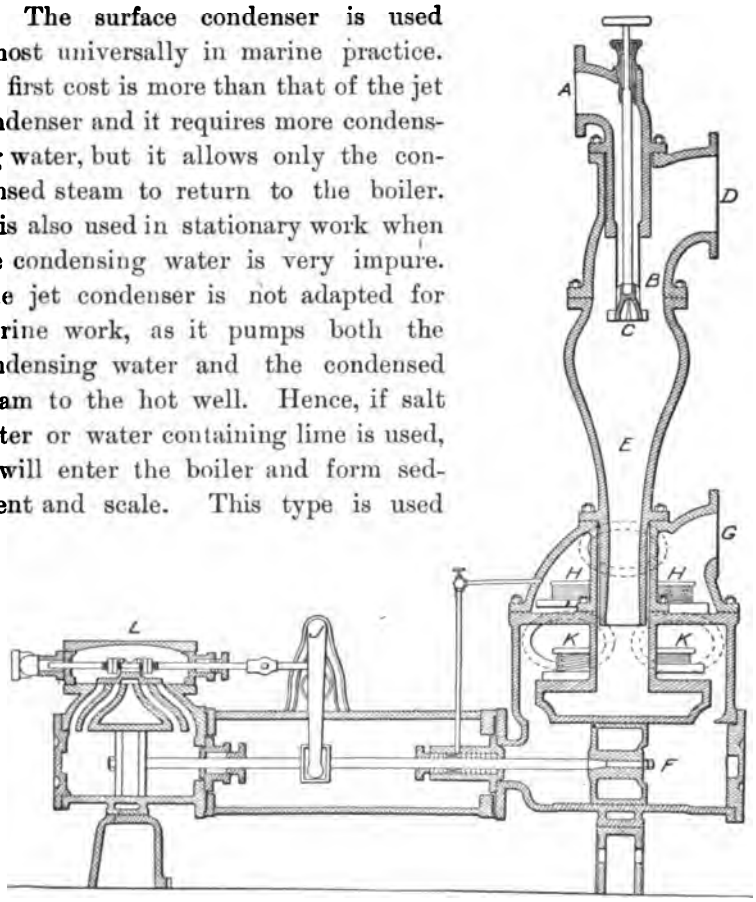


Fig. 29.

where fresh and moderately pure water is available.

It has been mentioned before that Watt always condensed the exhaust steam from his engines, and that when higher pres-

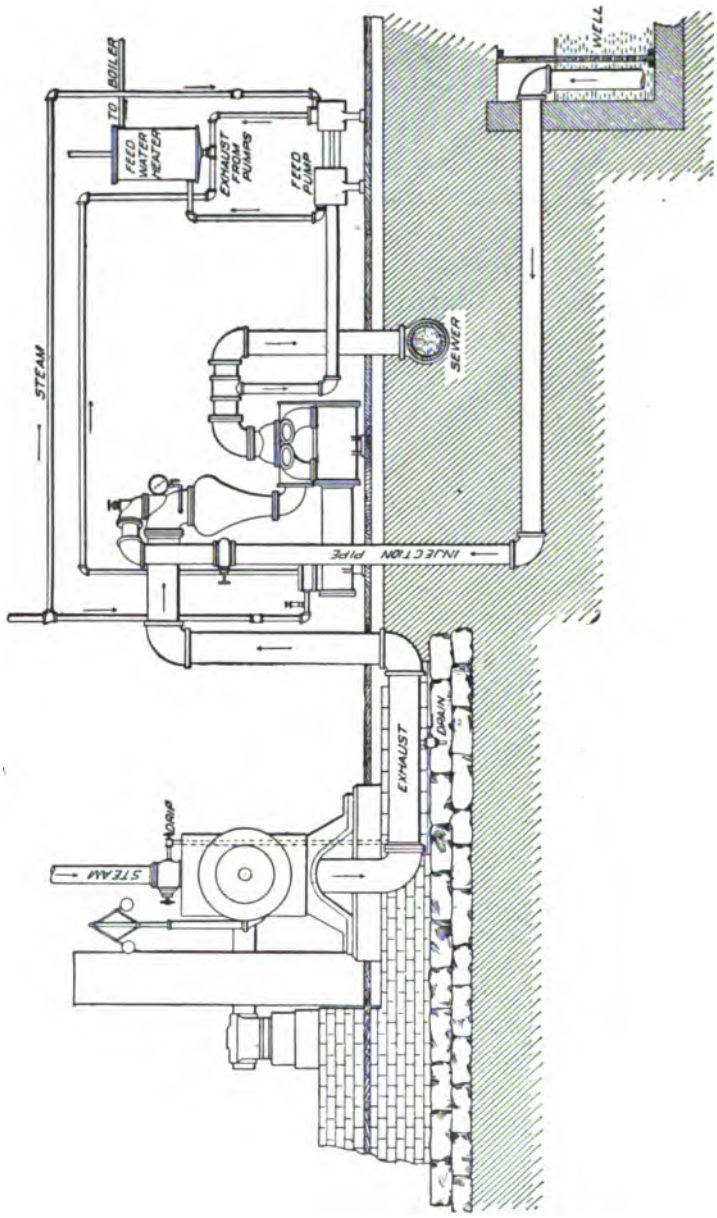

WELL
TO BOILER
FEED WATER HEATER
EXHAUST FROM PUMPS
FEED PUMP
SEWER
STEAM
INLET PIPE
EXHAUST
DRAIN
DRIP
STEAM

Fig. 30.

sures came into use some makers let the steam discharge into the atmosphere. This leads to the distinction between condensing and noncondensing engines. Both types are in common use, but the condensing engines are much more economical than the noncondensing, as far as fuel is concerned; but to condense the steam, considerable water is necessary, and condensing engines cost more and require more care. Consequently in some cases it is quite as economical, all things considered, to use the noncondensing engine.

COOLING TOWERS.

It sometimes happens that it is impossible to place a steam plant in close proximity to a natural water supply. In such cases the water necessary for the condenser (the circulating water) is expensive, and if the cost is very great it does not pay to add the condenser, because the cost of the circulating water might more than offset the gain from condensing. If, however, some means could be provided whereby the circulating water as it issues from the condenser could be cooled and then used over again in the condenser, the noncondensing engine could then be run condensing; thus taking advantage of all the benefits due to the use of reduced back pressure and heating of the feed water. This has been attempted by conducting the heated discharge water to a pond, where it is allowed to cool to a lower temperature before being used again. Another plan is to place in the yard or on the roof of the building large shallow pans, in which the water is cooled by being exposed to the atmosphere. These methods are unsatisfactory on account of the considerable area necessary and the slow action. In addition they are uncertain, because they are dependent upon atmospheric conditions.

A more efficient and at the same time more expensive process is to use a cooling tower or a water table. Fig. 31 shows the general arrangement of a cooling tower located upon the roof of a building. The discharge from the condenser is led, as shown by the arrows, to the top of the cooling tower, where it is cooled before being returned to the condenser. This cooling is effected by distributing the water, by a system of piping, to the upper edge of a series of mats or slats, over the surface of which the water

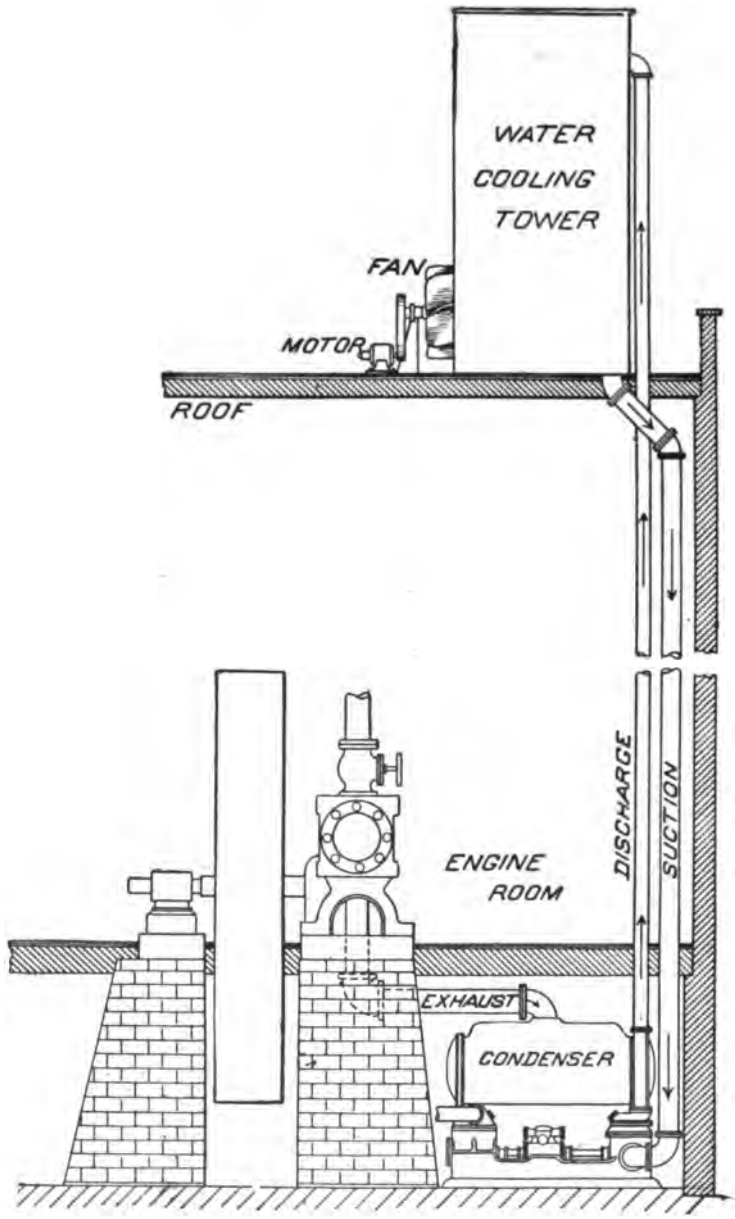
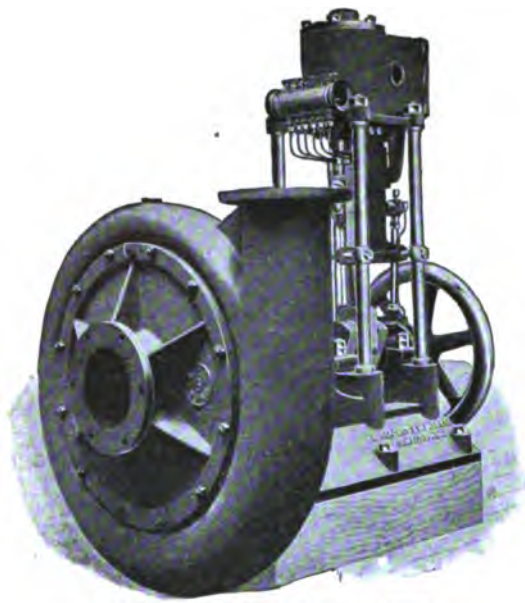
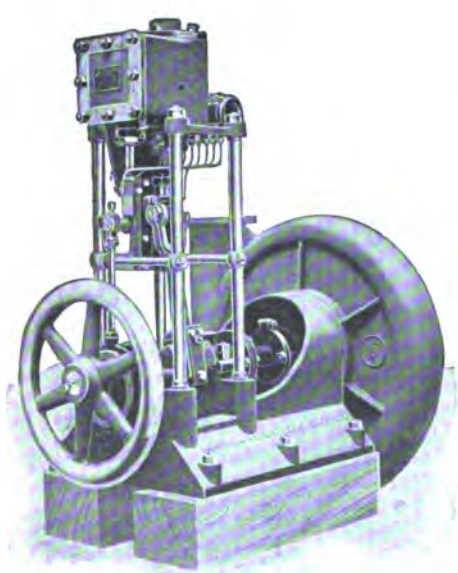

WATER
COOLING
TOWER
FAN
MOTOR
ROOF
DISCHARGE
SUCTION
ENGINE
ROOM
EXHAUST
CONDENSER

Fig. 31.



Side-Suction Engine-Driven Pump.

Class H Engine-Driven Pump.



Side-Suction Engine-Driven Pump.

flows in a thin film to a reservoir which is situated in the bottom of the cooling tower. The mats partially interrupt the flow, and by breaking up the water in small streams cause new portions to be exposed to the cooling effect of the air currents. The water from the reservoir then flows downward through the suction pipe, and is pumped by the circulating pump through the condenser. After passing through the condenser and absorbing heat from the exhaust steam, it rises through the discharge pipe and commences the circuit over again.

The tower may have several arrangements and be made of various materials. A satisfactory form is constructed of steel plates; within the tower are a large number of mats of steel wire cloth galvanized after weaving.

To assist in the cooling of the water, the air is often made to circulate rapidly by means of a fan, which forces the air into the lower part of the tower and upwards among the mats. This fan is usually of the ordinary type, and may be driven by an electric motor, a line of shafting, or by a small independent engine.

In case the fan is not used, the mats are arranged so that they are exposed to the atmosphere, as shown in Fig. 32. This of course necessitates the removal of the steel casing. Usually the fanless tower must be placed at the top of a high building, or in some position where the currents of air can readily circulate among the mats.

With an efficient type of cooling tower the water may be reduced from 30 to 50°, thus allowing a vacuum of from 22 to 26 inches. This will of course greatly increase the economy of the plant, and allow the heated feed water to be returned to the boiler.

The water table is usually made of wooden slats placed in the ground near the plant. After trickling over the slats and becoming cooled by the air, it collects in the bottom of the reservoir and is then pumped into the condenser.

THE FLY WHEEL.

It is evident that while the piston can push the crank around during part of the stroke, and pull it during another part, there are still two places (called dead points) at the ends of the stroke, where the pressure on the piston, no matter how great, can exert

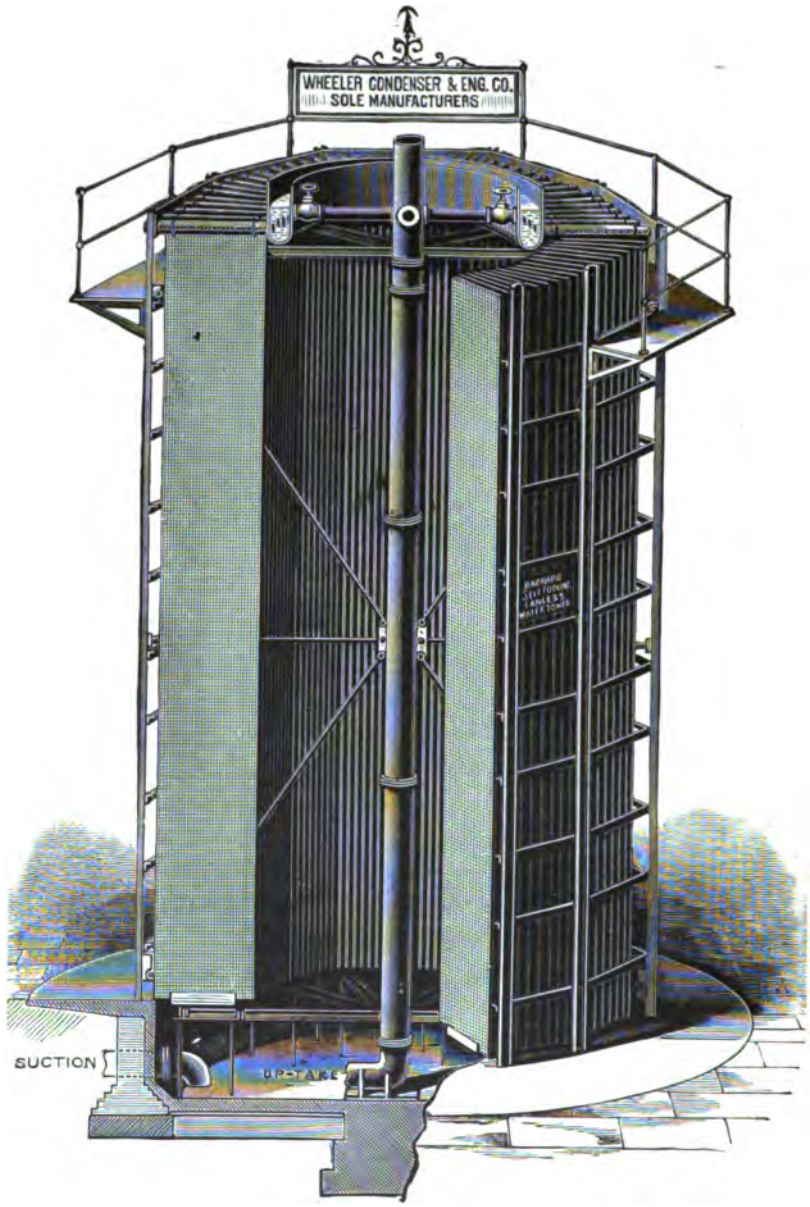

WHEELER CONDENSER & ENG. CO.
SOLE MANUFACTURERS
SUCTION
UPTAKE

Fig. 82.

no turning moment on the shaft. Therefore, if some means is not provided for making the shaft turn past these points without the assistance of the piston, it may stop. This means is provided in the fly wheel, which is merely a heavy wheel placed on the shaft. On account of the momentum of the fly wheel it cannot be stopped quickly, and therefore carries the shaft around until the piston can again either push or pull.

If a long period be considered, the mean effort and the mean resistance must be equal; but during this period there are temporary changes of effort, the excesses causing increase of speed. To moderate these fluctuations several methods are employed.

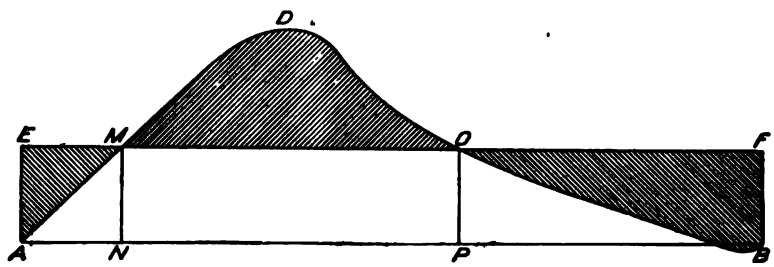


Fig. 33.

The turning moment on the shaft of a single cylinder engine varies, first, because of the change in steam pressure, and second, on account of the angularity of the connecting rod. Before the piston reaches mid-stroke the turning moment is a maximum, as shown by the curve, (Fig. 33). While near the ends of the stroke (the dead points) the turning moment diminishes and finally becomes zero. This, of course, tends to cause a corresponding change in the speed of rotation of the shaft. In order to have this speed as nearly constant as possible, and to give a greater uniformity of driving power, the engine may be run at high speed. By this means the inertia of the revolving parts, such as the connecting rod and crank, causes less variation. When the work to be done is steady and always in the same direction (as in most factories), a heavy fly wheel may be used.

The heavier the fly wheel, the steadier will be the motion. It is, of course, desirable in all factory engines to have steady motion, but in some it is more important than in others. For

instance, in a cotton mill it is absolutely necessary that the machinery shall move with almost perfect steadiness; consequently mill engines always have very large, heavy fly wheels. It is undesirable to use larger wheels than are absolutely necessary, because of the cost of the metal, the weight on the bearings and the danger from bursting.

If the turning moment which is exerted on the shaft from the piston could be made more regular, and if dead points could be avoided, it would be possible to get a steadier motion with a much smaller fly wheel.

If the engine must be stopped and reversed frequently, it is better to use two or more cylinders connected to the same shaft. The cranks are placed at such angles that when one is exerting its minimum rotative effort, the other is exerting its maximum turning moment; or, when one is at a dead center, the other is exerting its greatest power. These two cylinders may be identically the same, as is the case with most hoisting engines and with many locomotives; or the engine may be compound or triple expansion.

This arrangement is also used on engines, for mines, collieries, and for hoisting of any sort where ease of stopping, starting and reversing are necessary. Simple expansion engines with their cranks at right angles are said to be coupled.

The governor adjusts the power of the engine to any large variation of the resistance. The fly wheel has a duty to perform which is similar to that of the governor. It is designed to adjust the effort of the engine to sudden changes of the load which may occur during a single stroke. It also equalizes the variation in rotative effort on the crank pin. The fly wheel absorbs energy while the turning moment is in excess of the resistance and restores it while the crank is at or near the dead points. During these periods the resistance is in excess of the power.

The action of the fly wheel may be represented as in Figs. 33 and 34. It will be noticed that in Fig. 33 the curve of crank effort runs below the axis toward the end of the stroke. This is because the compression is greater than the pressure near the end of expansion, and produces a resultant pressure on the piston. In Fig. 34 the effect of compression has been neglected. Let us suppose that the resistance, or load, is uniform. In Fig. 33 the line

Class L Engine or Motor-Driven Pump.

Standard Vertical Pump.

(Shown by Courtesy of the Kingsford Foundry and Machine Works.)

Hydraulic Dredging Pump, Belt-Driven.

A B is the length of the semi-circumference of the crank pin, or it is the distance the crank pin moves during one stroke. The curve A M D O B is the curve of turning moment for one stroke. M N is the mean ordinate, and therefore A E F B represents the constant resistance. The effort and resistance must be equal if the speed is uniform; hence A E F B = A M D O B. Then area A E M + area O F B = area M D O. At A the rotative effort is zero because the crank pin is at the dead point; from A to N the turning moment is less than the resistance. At N the resistance and the effort are equal. From N to P the effort is in excess of the resistance. At P the effort and resistance are again equal. From P to B the resistance is greater than the effort. In other words, from A to N the work done by the steam is less than the resist-

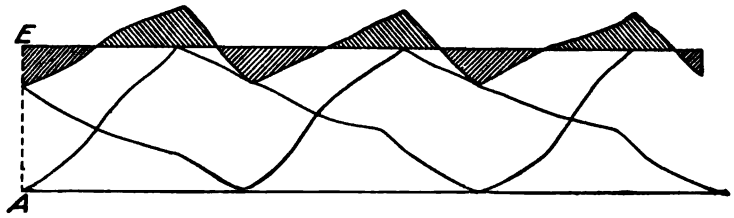


Fig. 34.

ance. This shows that the work represented by the area A E M must have been done by the moving parts of the engine. From N to P the work done by the steam is greater than the resistance, and the excess of energy is absorbed by or stored in the moving parts. From P to the end of the stroke, the work represented by the area O F B is done on the crank pin by the moving parts.

We know from the formula, $E = \frac{W V^2}{2g}$, that energy is proportional to the square of the velocity. Hence as W and g remain the same, the velocity must be reduced when the moving parts are giving out energy, and increased when receiving energy. Thus we see that the tendency of the crank pin is to move slowly, then more rapidly. The revolving parts of an engine have not sufficient weight to store this surplus energy, hence a heavy fly wheel is used.

In case there are two engines at right angles, two effort curves

must be drawn, as shown in Fig. 34. The mean ordinate A E is equal to the mean or constant resistance. There are two minimum and two maximum velocities in one stroke. The diagram shows that the variation is much less than for a single cylinder; hence a lighter fly wheel may be used.

The *weight of the fly wheel* depends upon the character of the work done by the engine. For pumping engines and ordinary machine work the effort need not be as constant as for electric lighting and fine work. In determining the weight of a fly wheel the diameter of the wheel must be known, or the ratio of the diameter of the wheel to the length of stroke. If the wheel is too large, the high linear velocity of the rim will cause too great a centrifugal force and the wheel is likely to break. In practice, about 6,000 feet per minute is taken as the maximum linear velocity of cast-iron wheels. When made of wood and carefully put together, the velocity may be taken as 7,000 to 7,500 feet per minute.

We know that linear velocity is expressed in feet per minute by the formula, $V = 2\pi R N$, or $V = \pi D N$.

Then if a wheel runs at 100 revolutions per minute, the allowable diameter would be,

$$6{,}000 = 3.1416 \times D \times 100$$

$$D = \frac{6{,}000}{3.1416 \times 100} = 19.1 \text{ feet.}$$

If a wheel is 12 feet in diameter the allowable speed is found to be,

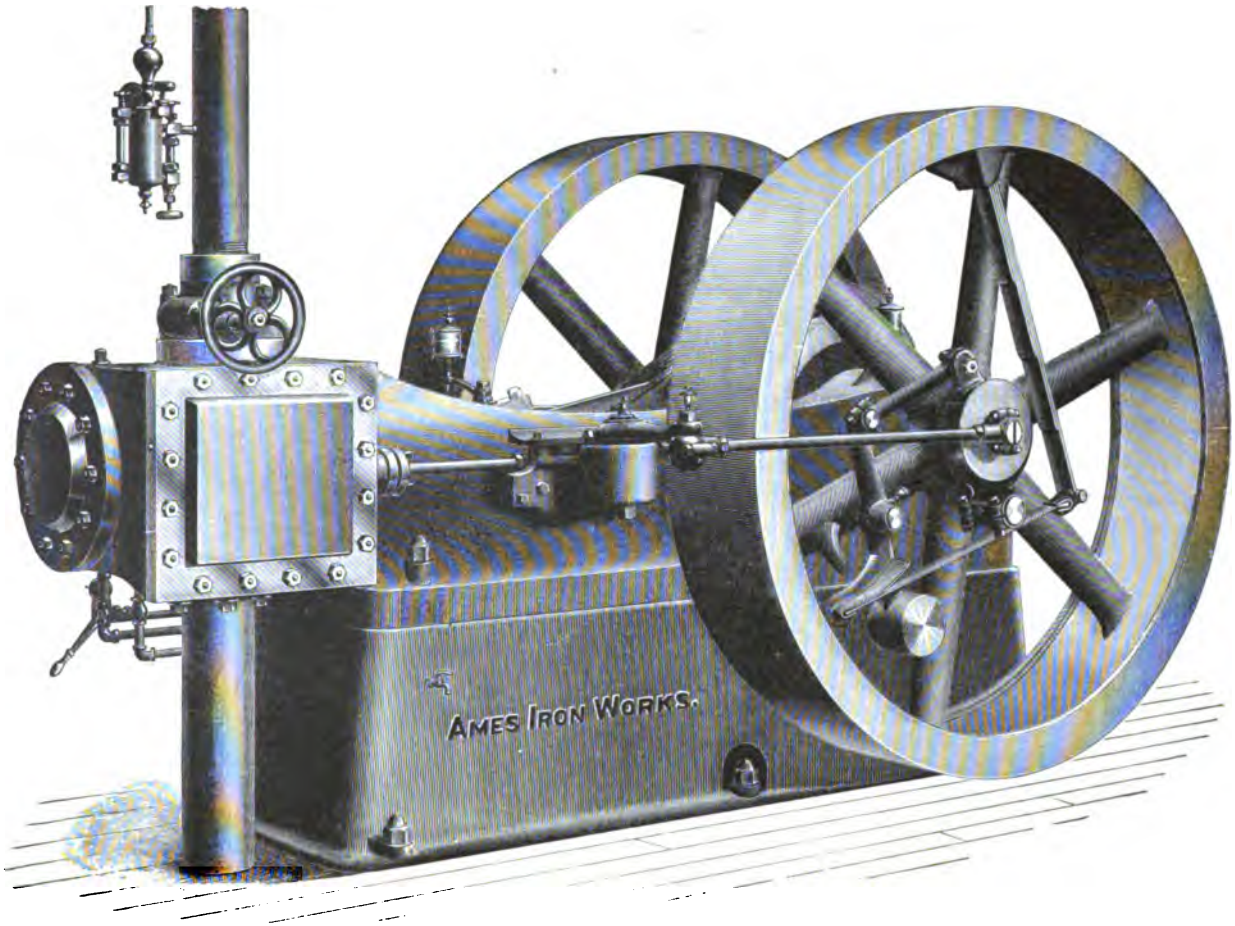
$$N = \frac{V}{\pi D}$$

$$= \frac{6{,}000}{3.1416 \times 12} = 159 \text{ revolutions per minute.}$$

It is usual to make the diameter a little less than the calculated diameter.

Having determined the diameter, the weight may be calculated by several methods. There are many formulas to obtain this result given by various authorities. One formula is given as follows:

$$W = \frac{C \times d^2 \times b}{D^2 \times N^2}$$



GOVERNOR SIDE OF AMES ENGINE

In the above, W = weight of the rim in pounds
d = diameter of the cylinder in inches
b = length of stroke in inches
D = diameter of fly wheel in feet
N = number of revolutions per minute

C is a constant which varies for different types and conditions.

Slide-valve engines, ordinary work,	C = 350,000
Corliss engines, ordinary work,	C = 700,000
Slide-valve engines, electric lighting,	C = 700,000
Corliss engines, electric lighting,	C = 1,000,000
Automatic high-speed engines,	C = 1,000,000

Example. Let us find the weight of a fly-wheel rim for an automatic high-speed engine used for electric lighting. The cylinder is 24 inches in diameter; the stroke is 2 feet. It runs at 300 revolutions per minute, and the fly wheel is to be 6 feet in diameter.

$$W = 1{,}000{,}000 \times \frac{(24)^2 \times 24}{36 \times 90{,}000}$$

$$W = 4{,}266 \text{ pounds}$$

Another example. A plain slide-valve engine for electric lighting is $20'' \times 24''$. It runs at 150 revolutions per minute. The fly wheel is to be 8 feet in diameter. What is the weight of its rim?

$$W = 700{,}000 \times \frac{400 \times 24}{64 \times 22{,}500}$$

$$W = 4{,}666 \text{ pounds.}$$

The weight of a fly wheel is considered as being in the rim. The weight of the hub and arms is simply extra weight. Then, if we know the weight of the rim and its diameter, we can find the width of face and thickness of rim. Let us assume the given diameter to be the mean of the diameter of the inside and outside of the rim.

Let b = width of face in inches
t = thickness of rim in inches
d = diameter of fly wheel in inches
.2607 = weight of 1 cubic inch of cast iron

Then,

$$W = .2607 \times b \times t \times \pi d$$
$$= b \times t \times .819\, d$$

Suppose the rim of a fly wheel weighs 6,000 pounds, is 9 feet in diameter, and the width of the face is 24 inches. What is the thickness of the rim?

$$t = \frac{W}{.819\ d\ b}$$

$$= \frac{6{,}000}{.819 \times 108 \times 24}$$

$$= 2.83 \text{ inches}$$

In this case the rim would probably be made $2\frac{13}{16}$ inches thick. The total weight, including hub and arms, would probably be about 8,000 pounds.

GOVERNORS.

The load on an engine is never constant, although there are cases where it is nearly uniform. While the engine is running at constant speed, the resistance at the fly-wheel rim is equal to the work done by the steam. If the load on the engine is wholly or partially removed, and the supply of steam continues undiminished, the force exerted by the steam will be in excess of the resistance. Work is equal to force multiplied by distance; hence, with constant effort, if the resistance is diminished, the distance must be increased. In other words, the speed of the engine will be increased. The engine will "race," as it is called. Also, if the load increases and the steam supply remains constant, the engine will "slow down."

It is evident, then, that if the speed is to be kept constant some means must be provided so that the steam supply shall at all times be exactly proportional to the load. This is accomplished by means of a governor.

Steam-engine governors act in one of two ways: they may regulate the *pressure* of steam admitted to the steam chest, or they may adjust the speed by altering the *amount* of steam admitted. Those which act in the first way are called throttling governors, because they throttle the steam in the main steam pipe. Those of the latter class are called automatic cut-off governors, since they automatically regulate the *cut-off*.

Theoretically, the method of governing by throttling the

steam causes a loss in efficiency, but the throttling superheats the steam, thus reducing cylinder condensation. By the second method the loss in efficiency is very slight, unless the ratio of expansion is already great, in which case shortening the cut-off causes more cylinder condensation. This subject will be taken up in detail later.

In most governors, centrifugal force, counteracted by some other force, is employed. A pair of heavy masses (usually iron balls or weights) are made to revolve about a spindle, which is driven by the engine. . When the speed increases, centrifugal force increases, and the balls tend to fly outward; that is, they revolve in a larger circle. The controlling force, which is usually gravity or springs, is no longer able to keep the balls in their former path. When, therefore, the increase is sufficiently great, the balls in moving outward act on the regulator, which may throttle the steam or cause cut-off to occur earlier.

With the throttling governor a balanced throttle valve is placed in the main steam pipe leading to the valve chest. If the engine runs faster than the desired speed, the balls are forced to revolve at a higher speed. The increase in centrifugal force will cause them to revolve in a larger circle and in a *higher plane*. By means of some mechanism (levers and gears) the spindle may be forced downward, thus partially closing the valve. The engine, therefore, takes steam at a lower pressure, and the power supplied being less, the speed falls slightly.

Similarly, if the load is increased, the engine slows down, which causes the balls to drop and open the valve more widely; steam at higher pressure is then admitted, and the speed is increased to the regular number of revolutions.

With the Corliss or Wheelock engine the governor of this type acts differently. Instead of throttling the steam in the steam pipe, the governor is connected to the releasing gear by rods. An increase of speed causes the releasing gear to unhook the disengaging link earlier in the stroke. This causes earlier cut-off, which of course decreases the power and the speed, since the amount of steam admitted is less. If for any reason the load increases, the governor causes the valves to be held open longer. The cut-off, therefore, occurs later in the stroke.

One of the most common forms of governor is similar to that invented by James Watt. It is called, from its appearance, the pendulum governor. It is shown in Fig. 35. To consider the theory of the pendulum governor, the masses of the balls are assumed to be concentrated at their centers, and the rods made of some material having no weight.

When the governor is revolving about its axis at a constant speed the balls revolve in a circle having a radius r. The distance from this plane to the intersection of the rods, or the rods produced, is called the height and is equal to h.

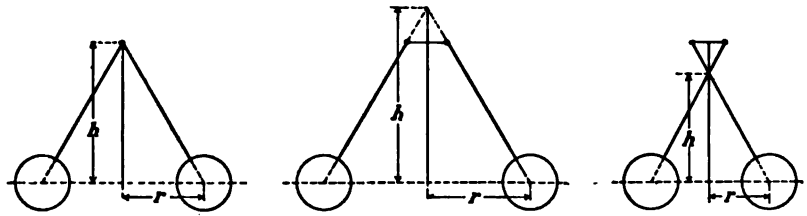


Fig. 35.

If the balls revolve faster, the centrifugal force increases, r becomes greater and h diminishes. We know that centrifugal force is expressed by the formula,

$$F = \frac{W v^2}{g r}$$

Then centrifugal force varies inversely as the radius.

While the pendulum is revolving, centrifugal force acts horizontally outward and tends to make the balls fly from the center; gravity tends to make the balls drop downward. In order that the balls shall revolve at a certain height, the moments of these two forces about the center must be equal, or the weight of the balls multiplied by their distance from the center must equal the centrifugal force multiplied by the height, or,

$$W \times r = F \times h$$

from which,

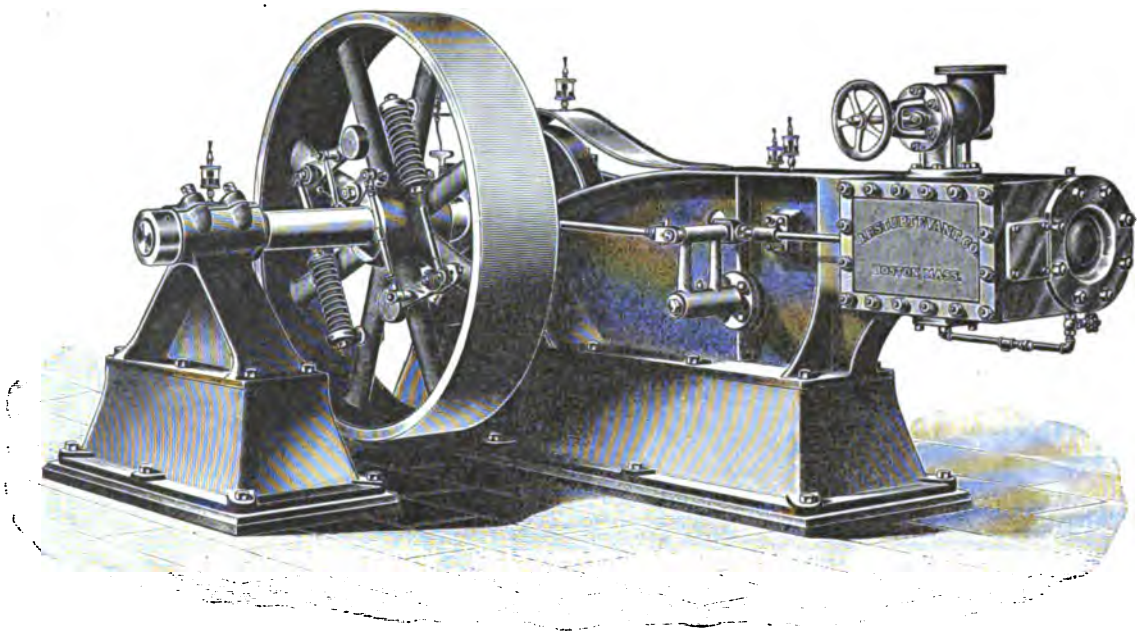
$$\frac{h}{r} = \frac{W}{F}$$

or,

$$\frac{h}{r} = \frac{W}{\frac{W v^2}{g r}} = \frac{g r}{v^2}$$

from which,

$$h = \frac{g r^2}{v^2}$$



SIDE-CRANK AUTOMATIC HORIZONTAL ENGINE

Now we know that the linear velocity of a point revolving in the circumference of a circle is expressed as $2\,\pi\,r\,N$ feet per second.

Then, $$h = \frac{g\,r^2}{v^2} = \frac{g\,r^2}{4\pi^2\,r^2\,N^2} = \frac{g}{4\pi^2\,N^2}$$

Since we know the values of g and π we can write the formula,

$$h = \frac{32.16}{4 \times 3.1416^2 \times N^2} = \frac{.8146}{N^2} \text{ feet, or}$$

$$h = \frac{9.775}{N^2} \text{ inches}$$

If N is the number of revolutions per minute,

$$h = \frac{2{,}932.56}{N^2} \text{ feet}$$

$$h = \frac{35{,}190.7}{N^2} \text{ inches}$$

From the above formula, we see that the height is independent of the weight of the balls or the length of the rod; it depends upon the number of revolutions. The height varies inversely as the square of the number of revolutions.

The ordinary pendulum governor is not isochronous; that is, it does not revolve at a uniform speed in all positions; the speed changes as the angle between the arms and the spindle changes.

The early form consisted of two heavy balls suspended by links from a pin connection in a vertical spindle, as shown in Figs. 36 and 37. The spindle is caused to revolve by belting or gearing from the main shaft, so that as the speed increases, centrifugal force causes the balls to revolve in a circle of larger and larger diameter. The change of position of these balls can be made to affect the controlling valves so that the admission or the throttling shall vary with their position. With this governor it is evident that for a given speed of the engine there is but one position possible for the governor; consequently one amount of throttling or one point of cut-off, as the case may be. If the load varies, the speed of the engine will change. This causes the position of the governor balls to be changed slightly, thus altering the pressure

But in order that the pressure or cut-off shall remain changed, the governor balls must stay in their new position. That is to say, the speed of the engine must be slightly changed. Thus with the old ball governors there was a slightly different speed for each load. This condition has been greatly improved by various modifications until now such governors give excellent regulation.

While the engine is running with a light load, the valve controlled by the governor will be open just enough to admit steam at a pressure that will keep the engine running at a given speed. Now, if the engine is heavily loaded, the throttle valve must be wide open. The change of opening is obtained by a variation in the height of the governor, which is caused by a change of speed. Thus we see that the governor can control the speed only within certain limits which are not far apart. The difference in the extreme heights of the governor must be sufficient to open the throttle its entire range. In most well-designed engines the speed will not vary more than 4 per cent; that is, 2 per cent above or below the mean speed.

From the formula $h = \frac{35{,}190.7}{N^2}$, we can compute the heights corresponding to given speeds as shown by the following table:

Number of Revolutions per Minute.	Height in Inches.	Variation of Height in Inches .2 per cent.
250	.563	.0225
200	.879	.035
175	1.149	.046
150	1.564	.062
125	2.252	.090
100	3.519	.140
75	6.256	.250
50	14.076	.563

In the above table the second column is found from the formula $h = \frac{35{,}190.7}{N^2}$. The third column is the variation in height for a speed variation of 4 per cent or 2 per cent either above or below the mean.

From the table we see that for a considerable variation of speed there is but slight variation in the height of the governor. Also for high speeds the height of the governor is so small that it would be difficult to construct it. The slight variation in height is too small to control the cut-off or throttling mechanism throughout the entire range.

Other disadvantages of the fly-ball governor are as follows: it is apparent that the valves must be controlled by the weight of the governor balls. In large engines this requires very heavy balls in order to quickly overcome the resistance of the valves. But these large balls have considerable inertia and will therefore be reluctant to change their speed with that of the engine. The

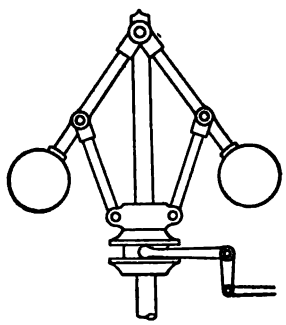


Fig. 36.

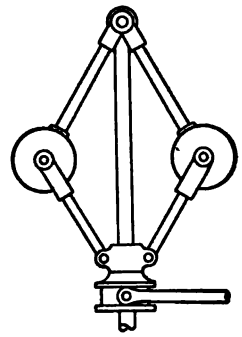


Fig. 37.

increased weight will also increase the friction in the governor joints, and the cramping action existing when the balls are driven by the spindle will increase this friction still further. All these things tend to delay the action of the governor, so that in all large engines the old-fashioned governor became sluggish. The balls had to turn slowly because they were so heavy; this was especially troublesome in high-speed engines.

To remedy these defects the weighted or Porter governor was designed. (See Fig. 38.) It has a greater height for a given speed, and the variation in height for a given variation of speed is greater. When a governor has this latter quality, that is, a great variation in height for a given variation of speed, it is said to be sensitive. By increasing this variation in height the sensitiveness is increased. Thus, if a governor running at 50 revolutions has a

variation in height of .57 inch, it is not as sensitive as one having a variation of 1 inch for the same speed.

In the weighted governor, the weight is formed so that the center of gravity is in the axis. It is placed on the spindle and is free to revolve. The weight adds to the weight of the balls, and thus increases the moment of the weight. It does not, however, add to the centrifugal force, and hence the moment of this force is unchanged. We may then say the weight adds effect to the weight but not to the centrifugal force, and as a consequence the height of the governor, for a given speed, is increased. If we let W equal the combined weight of the balls as before, and W′ equal the added weight, the moments are,

$$(W + W') \times r = F\,h$$

$$(W + W') \times r = \frac{W\,v^2}{g\,r} \times h$$

$$h = (W + W')\,r \times \frac{g\,r}{W\,v^2}$$

$$= \frac{(W + W')\,r^2\,g}{W \times 4\,\pi^2\,r^2\,N^2}$$

$$= \frac{(W \times W')}{W} \times \frac{g}{4\,\pi^2\,N^2}$$

We know that $\frac{g}{4\,\pi^2\,N^2} = \frac{.8146}{N^2}$.

Then $h = \left\{ \frac{W + W'}{W} \right\} \times \frac{.8146}{N^2}$.

Hence the height of a weighted governor is equal to the height of a simple pendulum governor multiplied by

$$\left\{ \frac{W + W'}{W} \right\} \text{ or } \left\{ 1 + \frac{W'}{W} \right\}.$$

For instance, if the height of a simple pendulum is 10 inches, and the weight of the balls equal to the added weight, the height will be,

$$h = \left\{ \frac{1 + 1}{1} \right\} \times \frac{.8146}{N^2}$$

$$= 2 \times \frac{.8146}{N^2}$$

Thus we see that if a weight equal to the combined weight of the balls is added, the height of the governor will be doubled.

We know that if the balls fall, the cut-off comes later. If the belt driving the governor slips off or breaks, the balls will drop, and, making the cut-off later, will allow the engine to "run away." To diminish this danger many governors are provided with some kind of safety stop, which closes the valve when the governor loses its normal action. Usually a trip is provided which the governor does not touch in its normal positions, but which will be released if the balls drop down below a certain point.

In another arrangement, instead of a weight, a strong spring is used, and this makes it possible to put the governor in any position.

Spring Governors. In many cases a spring is used in place of the weight. This type of governor is used frequently on throttling engines; it consists of a pendulum governor with springs added to counteract the centrifugal force of the balls. Thus the height and sensitiveness are increased. Fig. 39 shows the exterior view of a Waters governor, and Fig. 40 the same governor having the safety stop. In this governor the weights are always in the same plane, the variation in height being due to the action of the bell crank levers connecting the balls and spindle. When the balls move outward the spindle moves downward and tends to close the valve. The governor balls revolve by means of a belt and bevel gears. The valve and seat are shown in section in Fig. 41. The valve is a hollow cylinder with three ports, by means of which steam enters the valve. The seat is made in four parts, that is, there are four edges that the steam passes as it enters the valve. The valve being cylindrical and having steam on both sides is balanced, and because of the many openings only a small travel is necessary.

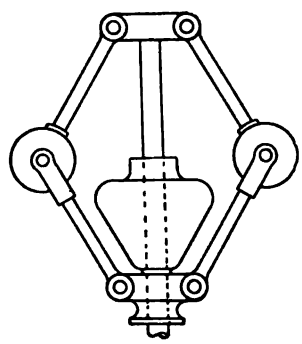


Fig. 38.

Shaft Governors. Usually some form of pendulum governor

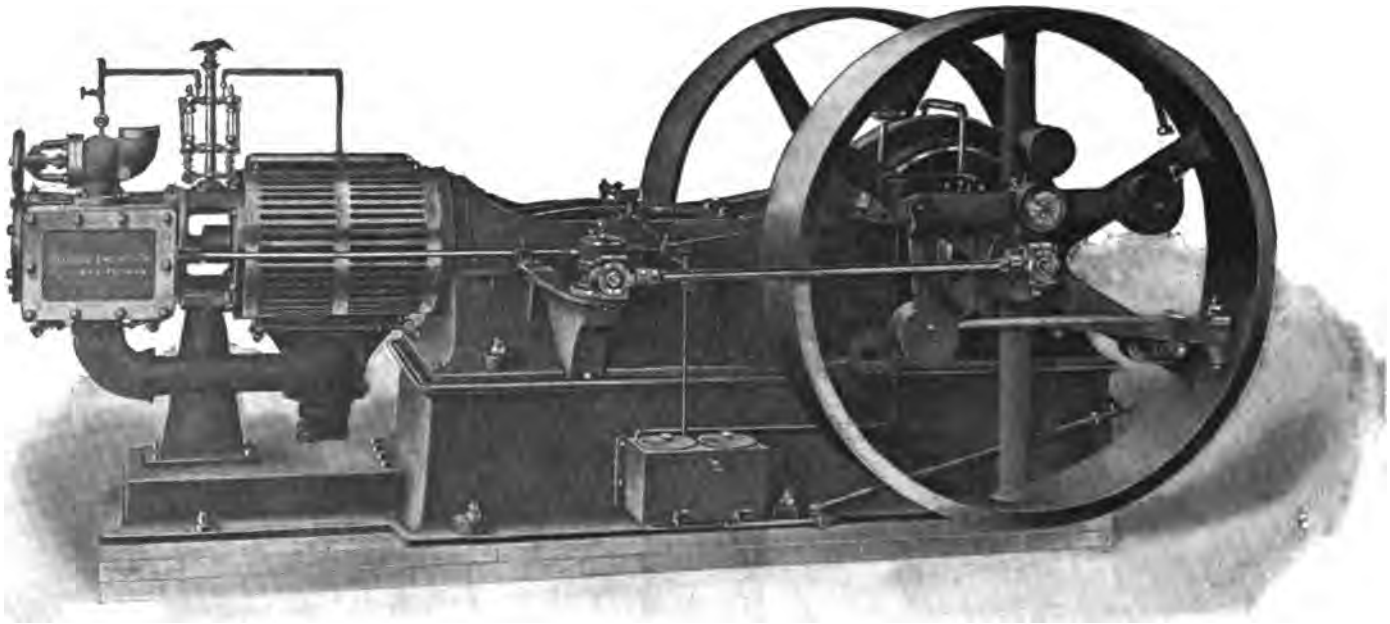
is used for throttling engines. For governing an engine by varying the point of cut-off, shaft governors are generally used; however, Corliss engines and some others use pendulum governors for this purpose. Cut-off governors are called shaft governors because they are placed on the main shaft; they are made in many forms, but the essential features of all are the same. Two pivoted masses or weights are arranged symmetrically on opposite sides of the shaft, and their tendency to fly outward when the speed increases is resisted by springs. The outward motion of the weights closes the admission valve earlier, and the inward motion closes it later. This change is effected by altering the position of the eccentric, either by changing the eccentricity or the angular advance.

Fig. 39.

Fig. 40.

Shaft governors are made in a great variety of ways, no two types being exactly alike. If the principles of a few types are understood, it is easy to understand others. The following illustrates two common methods of shifting the eccentric.

Buckeye Engine Governor. The valve of the Buckeye engine is hollow and of the slide valve type. The cut-off valve is inside. The change of cut-off is due to the alteration of the angular advance. The arrangement of the parts which effect the change of angular advance is shown in Fig. 42. A wheel which



SKINNER TANDEM COMPOUND ENGINE.

contains and supports the various parts of the governor is keyed to the shaft. Two arms, having weights A A at the ends, are pivoted to the arms of the wheel at *b b*. The ends having the weights are connected to the collar on the loose eccentric C by means of rods B B.

When the weights move to the position indicated by the dotted lines, the eccentric is turned on the shaft about a quarter of a revolution in the direction in which the engine runs. That is, the eccentric is advanced or the angular advance is increased. Now we know that if the angular advance is increased, cut-off occurs earlier. This is shown by the table on page 12 of "Valve Gears." If the engine had a single plain slide valve the variation of the angular advance would produce too great a variation of lead; but as this engine has a separate valve for cut-off, admission is not altered by the cut-off valve.

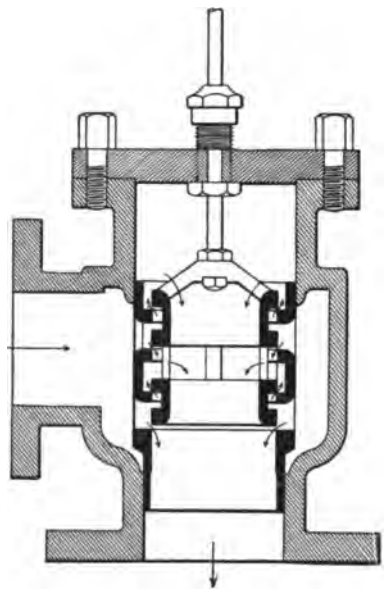


Fig. 41.

The springs F F balance the centrifugal force of the weights. The weights A A are varied to suit the speed; the tension on the springs is altered by means of the screws *c c*. Auxiliary springs are added in order to obtain the exactness of regulation necessary for electric lighting. These springs tend to throw the arms outward, but act only during the inner half of this movement.

The Straight-Line Engine Governor. Fig. 43 shows the governor of the straight-line engine. It has but one ball, B, which is linked to the spring S and to the plate D E, on which is the eccentric C. When the ball flies outward in the direction indicated by the arrow F, the eccentric is shifted about the pivot O; the links moving in the direction of arrow H. The ball is heavy and at a considerable distance from the center; hence it has a great centrifugal force, and the spring must be stiff.

The governor of the Buckeye engine alters the cut-off by changing the *angular advance*. The straight-line engine governor changes the *travel* of the valve. Shaft governors which alter the cut-off by changing the valve travel are very common.

LUBRICATION.

If two pieces of cast iron, just as they come from the foundry, are rubbed together, they will not slide over each other easily, because of little projections. If this same iron is filed or planed,

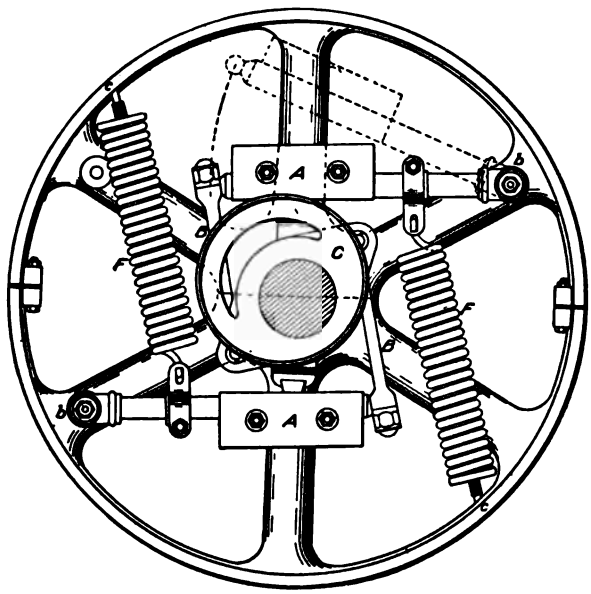
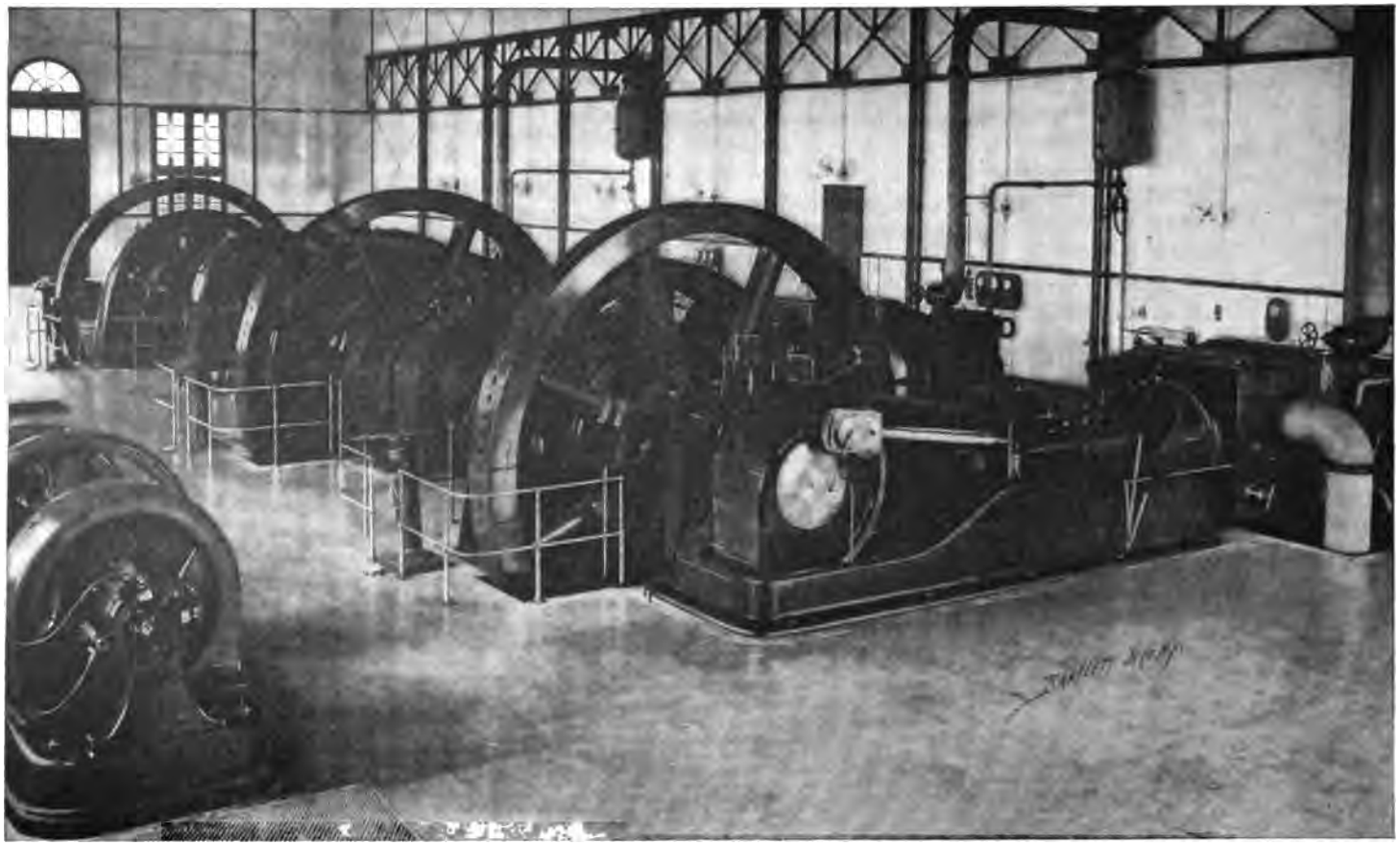


Fig. 42.

the pieces will slide much more easily. This is because the rough places have been smoothed, or filled up with dust. If now we put some engine oil on the pieces, they will slide very easily. This is because the more minute depressions have been filled up and the whole surface is made comparatively smooth. No matter how carefully we might plane and polish any surface, a microscope would show that it was still a little rough.

One cause of loss of power in the steam engine is friction. In all engines there are so many moving parts that it is of great importance that friction should be reduced as much as possible. This is



750 HORSE-POWER TANDEM COMPOUND ENGINES WITH DIRECT-DRIVEN ELECTRIC GENERATORS.
(Built by McIntosh, Seymour & Company.)

done by making the surfaces in contact smooth and of ample size; also making them of different metals and using oils or other lubricants. The effect of the lubricant is to interpose a thin film between the surfaces. This prevents their coming into actual contact. If the oil is too thin or the pressure too great, the lubricant is squeezed out and the metal surfaces come in contact.

Thus we see that there are certain qualities which a lubricant must have. They are as follows:

The lubricant must be sufficiently fluid, so that it will not itself make the bearing run hard.

It must not be too fluid or it will be squeezed out from between the bearing surfaces. If this happens, the bearing will

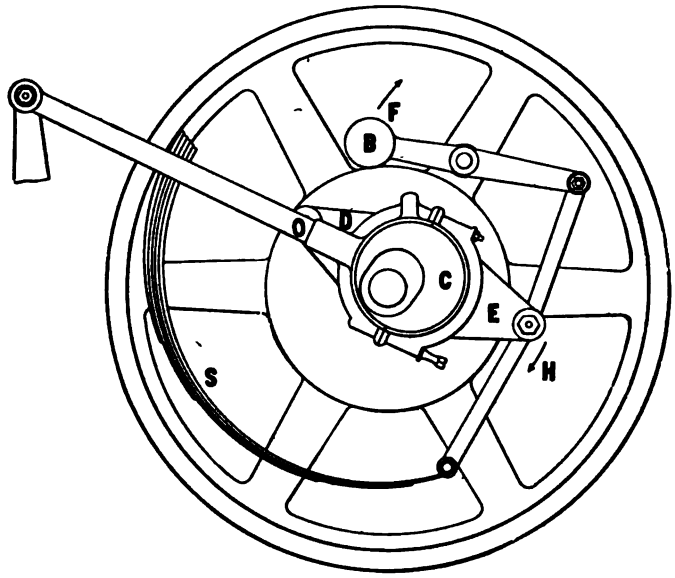


Fig. 43.

immediately begin to heat and cut. The heating will tighten the bearing, and will thus increase the pressure and the cutting.

It must not gum or dry when exposed to the air.

It must not be easily decomposed by the heat generated. If it should be decomposed, it might form substances which would be injurious to the bearings.

It must not take fire easily.

It must contain no acid, and should form no acid in decomposing, as acids corrode the bearings.

Both *mineral* and *animal* oils are used as lubricants. Formerly animal oils were used entirely, but they were likely to decompose at high temperatures and form acids. It is important in using high-pressure steam to have "high-test oils," that is, oils which will not decompose or volatilize at the temperature of the steam. It was the difficulty of getting such oils which made great trouble when superheated steam was first used. Mineral oils will stand these temperatures very readily, and even if they do decompose, they form no acids.

The Liquid Lubricants, whether of animal, vegetable or mineral origin, may be used for ordinary bearings, but for valves and pistons heavy mineral oils only are suitable.

Solid Lubricants. *Graphite* is used as a lubricant. It is well adapted for heavy pressures when mixed with certain oils. It is especially valuable for heavy pressures and low velocities.

Metalline is a solid compound, containing graphite. It is made in the form of solid cylinders, which are fitted to holes drilled into the surface of the bearing. When a bearing is thus fitted no other lubricant is necessary.

Soapstone in the form of powder and mixed with oil or fat is sometimes used as a lubricant. Soap mixed with graphite or soapstone is often used where wood is in contact with wood or iron.

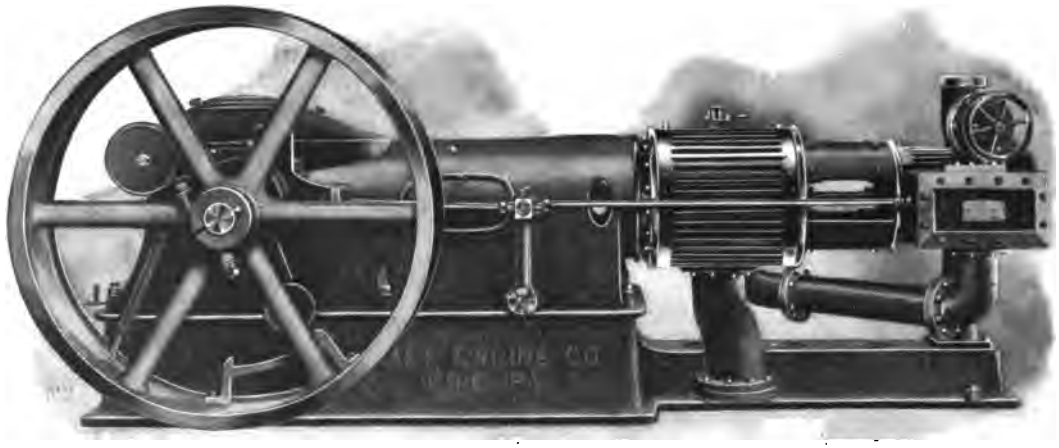
A preparation called *Fiber Graphite* is used for self-lubricating bearings. It is made of finely divided graphite mixed with fibers of wood. It is pressed in molds and afterward fitted to bearings.

For great pressure at slow speed, graphite, lard, tallow and other solid lubricants are suitable. If the pressure is great and the speed high, castor, sperm and heavy mineral oils are used.

For low pressure and high speed, olive, sperm, rape and refined petroleum give satisfaction.

In ordinary machinery, heavy mineral and vegetable oils and lard oil are good. The relative value of various lubricants depends upon the prevailing conditions. Oil that is suitable for one place might not flow freely enough for another.

The quality of oil is of great importance. In many branches



TANDEM COMPOUND ENGINE

of industry it is imperative that the machinery run as perfectly as possible. On this account and because of the high cost of machinery, only first-class oil should be used. The cylinder oil especially, should be high grade, because the valves, piston and piston rods are the most delicate parts of the engine.

Engines are lubricated by means of oil cups and wipers placed on the bearings wherever required. They are made in many forms, dependent upon the manufacturers. Commonly the oil cup is made with a tube extending up through the oil. A piece of lampwick or worsted leads from the oil in the cup to the tube. Capillary attraction causes the oil to flow continuously and drip down the tube. When not in use, the lampwick should be withdrawn.

Fig. 44.

The needle oil cup differs from the capillary oil cup in that a small wire or needle extends through the tube and oil; one end rests on the journal to be lubricated. The needle should fit the tube closely, so that when the machinery is at rest no oil will flow. When revolving, the shaft gives the needle a wabbling motion which makes the oil flow. To increase the supply, a smaller needle is used.

The oil cup shown in Fig. 44 is simple and economical. The opening of the valve is regulated by an adjustable stop. The oil may be seen as it flows drop by drop. The cylindrical portion is made of glass, so that the engineer can see how much oil there is in the cup without opening it.

A form of wiper crank pin oiler is shown in Fig. 45. The oil cup is attached to a bracket. The oil drops from the cup into a sheet of wicking or wire cloth and is removed at each revolution of the crank pin by means of the cup which is attached to the end of the connecting rod.

Fig. 46 shows a centrifugal oiling device. The oil flows from the oil cup through the tube to the small hole in the crank

pin by centrifugal force. It reaches the bearing surface by means of another small hole.

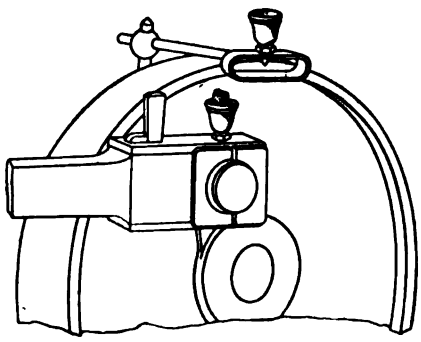


Fig. 45.

In oiling the valve chest and cylinder the lubricant must be introduced against the pressure of the steam. This can be done in several ways, in each of which it is introduced into the steam before it reaches the valve chest and is carried to the surfaces to be lubricated.

The oil can be forced into the steam pipe by a small hand pump or in large engines by an attachment from the engine itself. The supply of oil is, of course, intermittent if the pump is driven by hand, but continuous and economical if driven by the engine.

Sight Feed Lubricators. The most common device for feeding oil to the cylinder is that which introduces the oil drop by drop into the steam when it is in the steam pipe or steam chest. The oil becomes vaporized and lubricates all the internal surfaces of the engine.

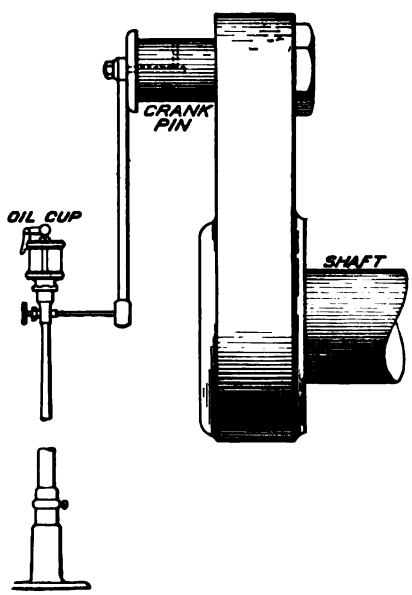
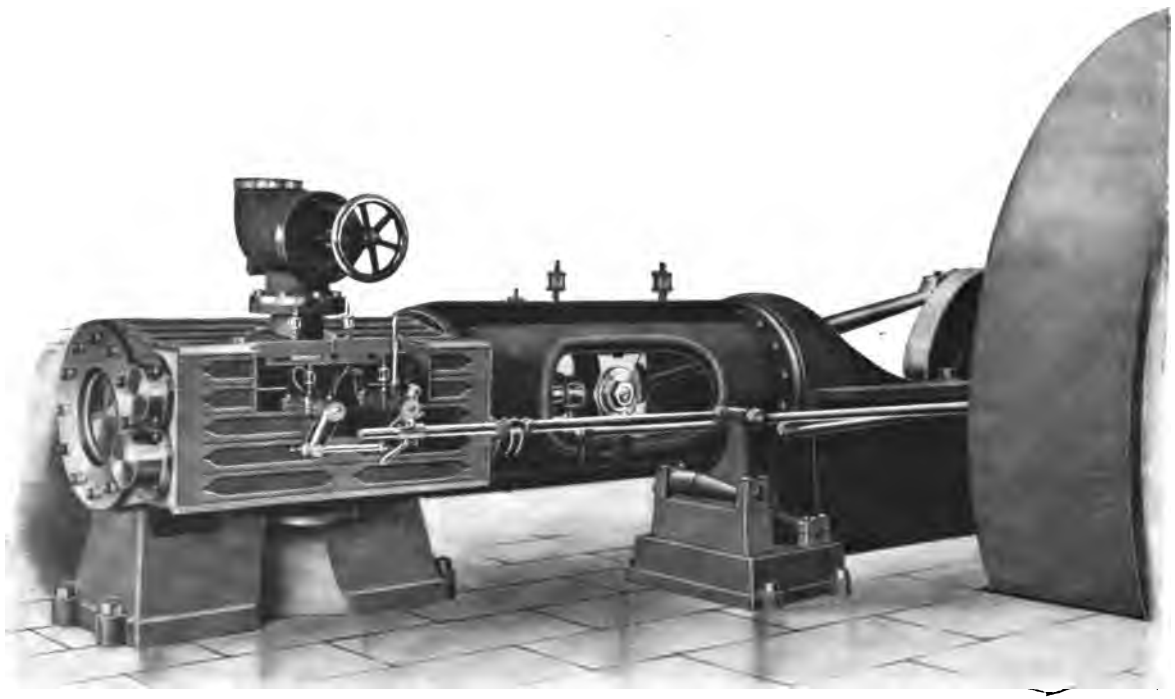


Fig. 46.

Fig. 47 shows the section of a sight feed lubricator. The reservoir O is filled with oil. The pipe B, which connects with the steam pipe, is partly filled with condensed steam, which flows down the small curved pipe E to the bottom of the chamber O. A small portion of the oil is thus displaced and flows from the top of the reservoir O down the tube F, by the



FITCHBURG ENGINE.

regulating valve D, and up through the glass tube S, which is filled with water. It enters the main steam pipe through the connection A. The gage glass G indicates the height of water in the chamber O. To fill the lubricator, close the regulating valve D and the valve in pipe B; the oil chamber can then be drained and filled. If the glass S becomes clogged it may be cleaned by shutting valve D and opening the small valve H. This will allow steam to blow through the glass. After cleaning close valve H and allow glass S to become filled with water before opening the feed valve. The amount of oil fed to the cylinder can be regulated by opening D (Fig. 47) the proper amount. The exact quantity of oil necessary for the engine is not easily determined. For ordinary sizes it is between one drop in two minutes and two drops per minute.

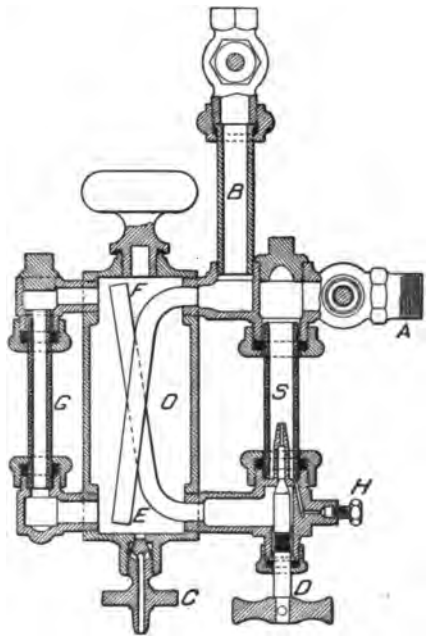


Fig. 47.

Graphite is an excellent lubricant and can be introduced into the cylinder dry or mixed with some heavy grease. It has been used extensively because of the trouble which cylinder oil gives in the exhaust and in the boilers of condensing engines.

In slow-speed engines it is not hard to attend to the oiling; all the parts are moving slowly and can be readily examined and oiled. Many high-speed engines run so fast that it is impossible to examine the various parts, and special means must be provided for lubricating. It is specially important in high-speed engines that there should be no heating. High-speed engines are generally used for electric lighting, and it is absolutely essential that they be kept running at the required speed to avoid flickering lights. Thus, while there is greater liability to heating in high-

speed engines, there is also much greater loss in case heating compels the stopping of an engine.

In order to avoid the danger of forgetting to oil a bearing of a high-speed engine, it is customary to have all the bearings oiled from one place. All the oil is supplied to one reservoir and from this reservoir pipes lead to all bearings. If this is not done, large oil cups are supplied, as a rule, so that oiling need not be attended to as frequently.

In some high-speed engines the moving parts are enclosed and the crank runs in a bath of oil. This secures certain oiling and is very effective. All the bearings may be inside this crank case, so that all are oiled in this way. It is impossible for a careless engineer to overlook one point and so endanger the whole engine.

STEAM TURBINE.

The very earliest records of the steam engine describe a form of steam turbine. It consisted of a hollow sphere, as shown in Fig. 48, mounted on trunnions, through which steam was admitted to the interior. This steam escaped through pipes bent tangentially to the equator line of the sphere. The force of the escaping steam reacted upon the sphere, causing it to revolve on its trunnions. Many centuries later, in 1629, Bianca, an Italian, invented a rotary engine (Fig. 49), in which a jet of steam struck the vanes of a wheel, and thus forced it around in much the same way that a jet of water acts on a Pelton water-wheel. These engines were of little, if any, practical value, and used an immense quantity of steam.

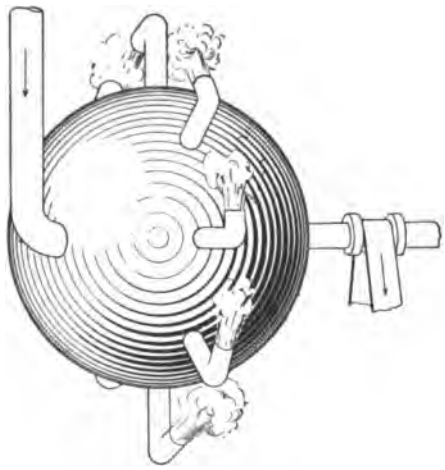
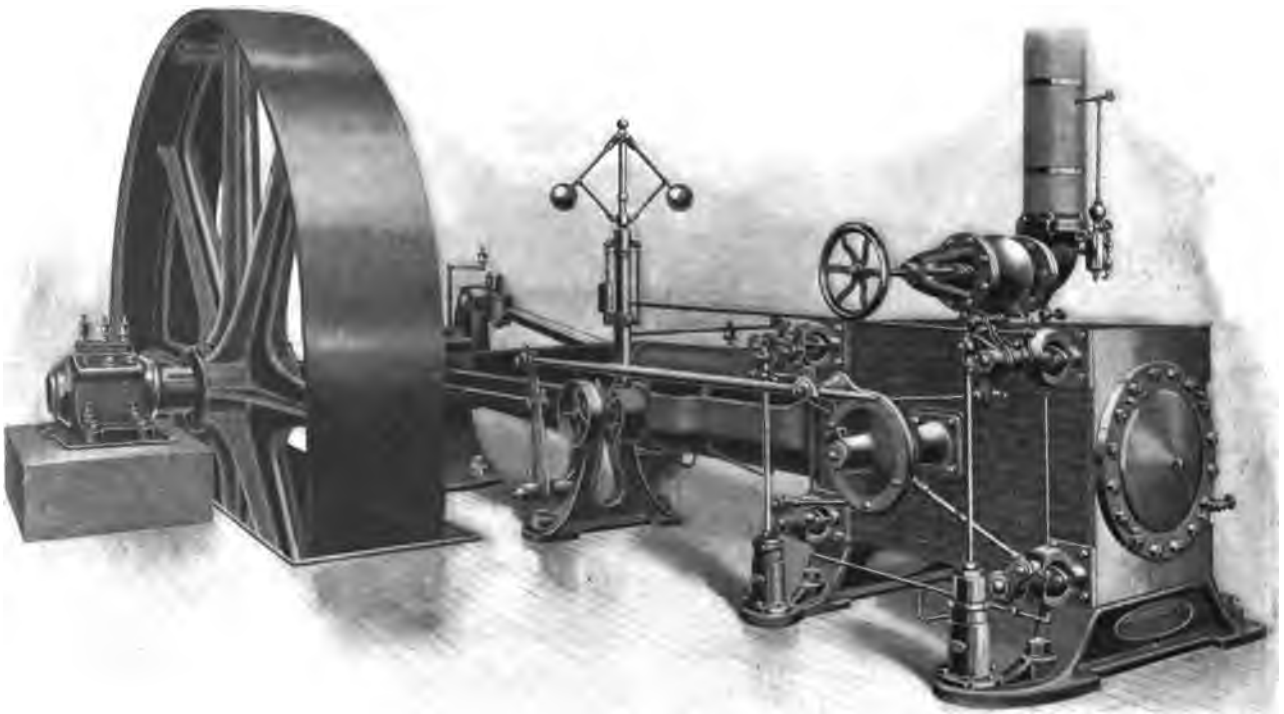


Fig. 48.



FISHKILL-CORLISS ENGINE

In 1705 the reciprocating engine was introduced, and by means of Watt's inventions became so efficient that the development of the rotary engine was out of the question. It will be remembered that Watt introduced the expansive use of steam in the reciprocating engine, which at this time could not be accomplished in the rotary engine, and until within the last few years practically nothing was done to develop the turbine.

Since the days of Watt there has been but one important thermodynamic improvement in the reciprocating engine; namely,

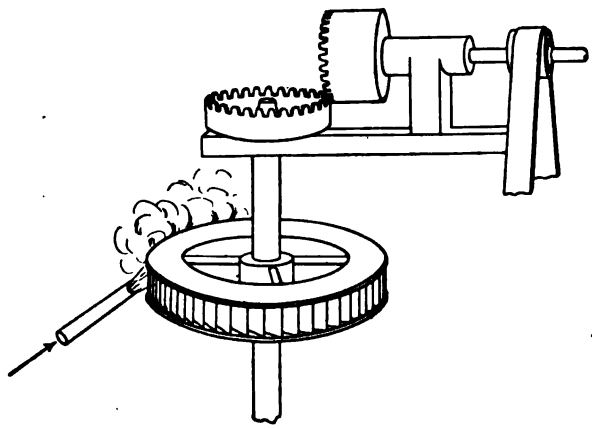


Fig. 49.

the introduction of compound expansion. All other improvements have been in the nature of mechanical devices, and it seems reasonable to suppose that the greatest developments of the future may possibly be in the production of some type other than the reciprocating engine.

In 1883 De Leval invented a successful turbine for running a cream separator, and a short time later Parsons introduced another. Both of these engines employed the expansive force of steam, but each derived this force in a different way.

Since 1883 the development of the turbine has been very rapid. The first engine introduced by De Leval, although far ahead of the earlier forms, was still very wasteful of steam; but now such improvements have been made that their steam consumption compares very favorably with the consumption of good reciprocating engines.

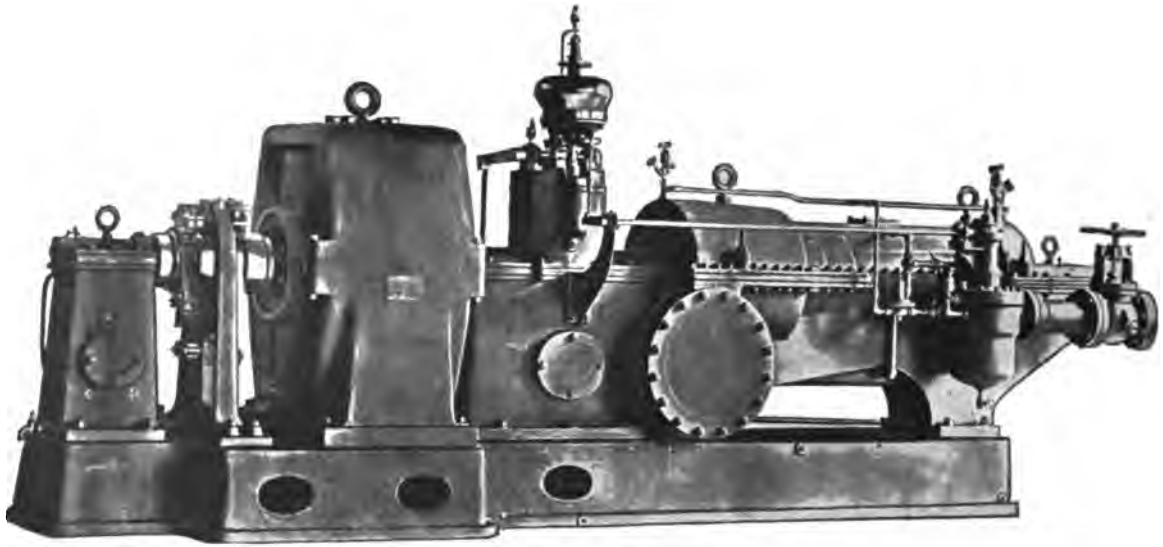
A modern turbine is a tremendously high-speed engine. It does not derive its power from the static force of steam expanding behind a piston, as in the reciprocating engine, but in this case the expanding steam produces kinetic energy of the steam particles. These particles receive a high velocity by virtue of the expansion, and, acting upon the vanes of a wheel, force it around at a high speed of rotation in some such manner as a stream of water rotates a water-wheel.

In the reciprocating engine the expansion produces a force which presses on the piston. In the rotary engine the expansion produces velocity in a jet of steam. This is the fundamental difference between the two forms.

The essential principles of water turbines are equally true of steam turbines. The jet must strike the vanes without a sudden shock, and must leave them in another direction without any sharp deflections. For maximum efficiency the De Leval engine should have a jet velocity equal to one-half the linear velocity of a point on the wheel-rim; for the Parsons these velocities should be equal. If the velocity of steam is 8,000 feet per second, it is easily seen that even one-half of this would cause too great a speed of rotation for safety. It would be difficult to build a wheel that would be strong enough to withstand the centrifugal force at this high speed. It becomes necessary, therefore, to reduce the speed to the limits of safety, and run under a slightly less efficiency.

At such high speed the shaft and wheel should be perfectly balanced, in order that its center of gravity may exactly coincide with the axis of rotation. In practice it has been found impossible to balance the shaft perfectly; and in order that it may revolve about its center of gravity, various means are adopted to overcome the rigidity of an ordinary shaft and bearing. This makes high speed of rotation possible without any apparent vibration.

De Leval Turbine. The De Leval turbine shown in Fig. 50 consists of a wheel with suitably shaped buckets, against which a jet of steam is directed. The buckets are on the rim of the wheel and are surrounded by a casing B, which prevents the escape of the steam until it has done its work. A piece of this casing is cut away at A in order to show the buckets. The steam



WESTINGHOUSE-PARSONS STEAM TURBINE DIRECT CONNECTED TO ALTERNATOR.

from the nozzle strikes these buckets and is deflected. Thus by the impact of the jet and the reaction due to its deflection, the wheel is caused to revolve at a high speed.

There are usually four nozzles that supply steam to the turbine, one of which is shown in section at D. These nozzles are small at the throat and diverge outward. By making them of the right length and with the proper amount of divergence, the steam can be expanded from the pressure of admission to the

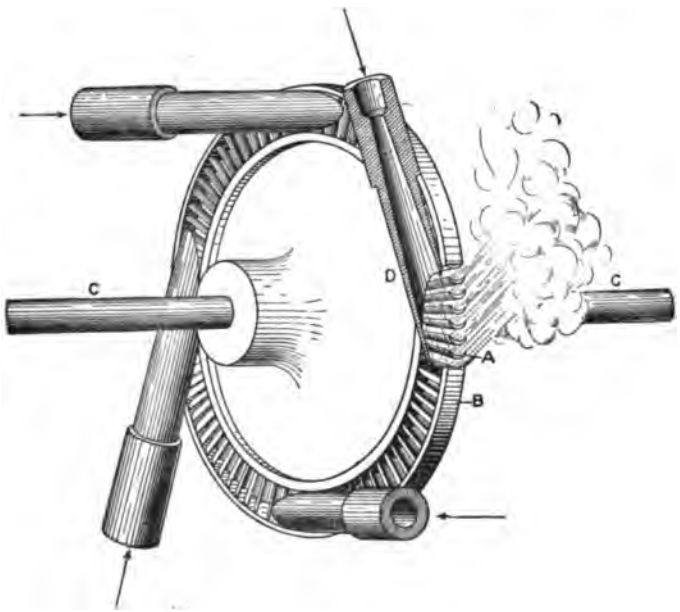


Fig. 50.

pressure of the condenser. Complete expansion is obtained in this diverging nozzle, and the steam leaves it at the exhaust pressure. The steam then works only by virtue of its high velocity.

This turbine has a long, flexible shaft C which can deflect enough to make up for any eccentricity of the center of gravity of the shaft, and thus allow the shaft to revolve about its center of gravity and still have rigid bearings at the end.

Admission is regulated by a throttle-valve, controlled by a fly ball governor.

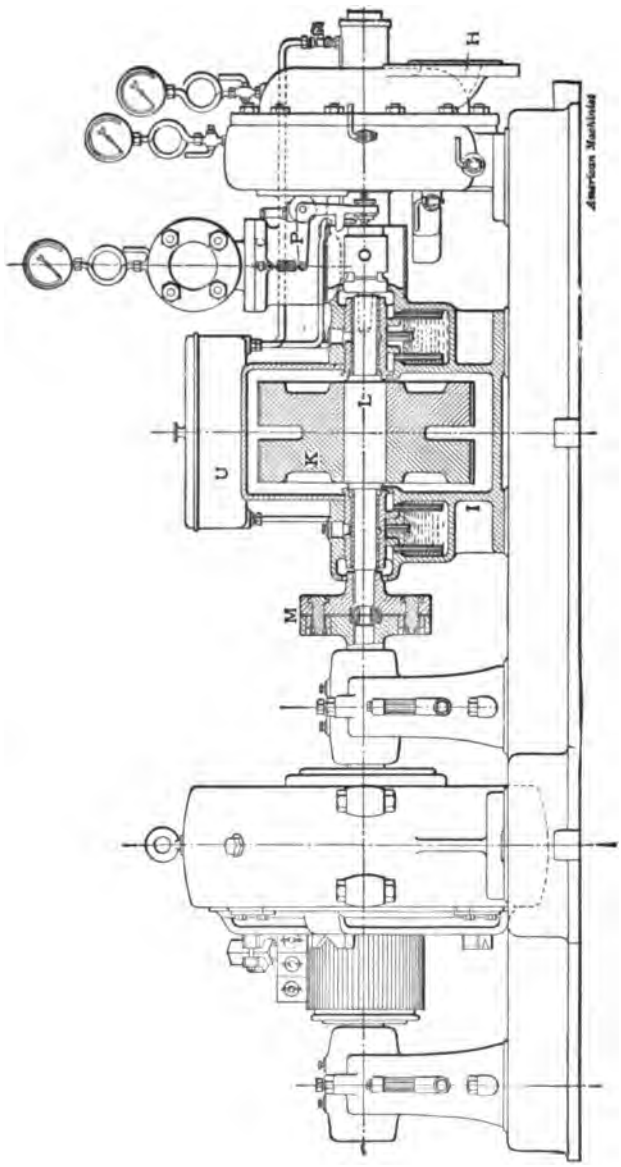


Fig. 51.

Fig. 51 shows a De Leval turbine connected with a generator.

The Parsons Turbine. Fig. 52 is a longitudinal section of a Westinghouse-Parsons turbine. Steam enters the chamber A and passes through the turbine vanes to the exhaust chamber B. The vanes are arranged as shown in Fig. 53, and consist of alternate sets, one stationary, the next movable. The steam strikes one and is deflected to the next; thus the action and the reaction occurring in rapid succession cause the movable sets, which are fixed to the shaft, to rotate at a high speed. As the steam passes the different sets of blades, the volume of the passages increases to correspond with the expansion of the steam. In the De Leval the steam was expanded entirely before reaching the wheel, but in the Parsons the expansion is accomplished in the engine itself. As the steam enters the chamber A (see Fig. 52) it presses on the turbine vanes and it also presses equally and in the opposite direction on C, which is really a piston fixed to the shaft. Thus we see that the pressure to the right is equal to the pressure to the left, and there is no end pressure on the bearing of the shaft. C_1 and C_2 balance the steam pressure in the chambers E and G. At H is a bearing which serves to maintain a correct adjustment of the balance pistons C. There is probably some escape of steam past these balancing pistons, but it is small. The exhaust steam at B presses the turbine toward the left, and would cause an end pressure on the bearing were it not that the pipe K opens a communication between the exhaust chamber B and the back of the balancing pistons, which makes the pressure equal at both ends.

The bearing consists of a gun-metal sleeve surrounded by three concentric tubes. There is a small clearance between these tubes which fills with oil and permits the bearing to run slightly eccentric to counteract any lack of balance in the shaft. Thus the shaft may revolve about its center of gravity, and this oil bearing serves the same purpose as the De Leval flexible shaft.

At P is shown a by-pass valve by means of which live steam may be admitted to the space E, if desirable. Of course this reduces one stage of the expansion, with a corresponding loss of economy, but will increase the power of the turbine. If the condenser fails on a condensing turbine it may still be run at full load by opening the by-pass valve.

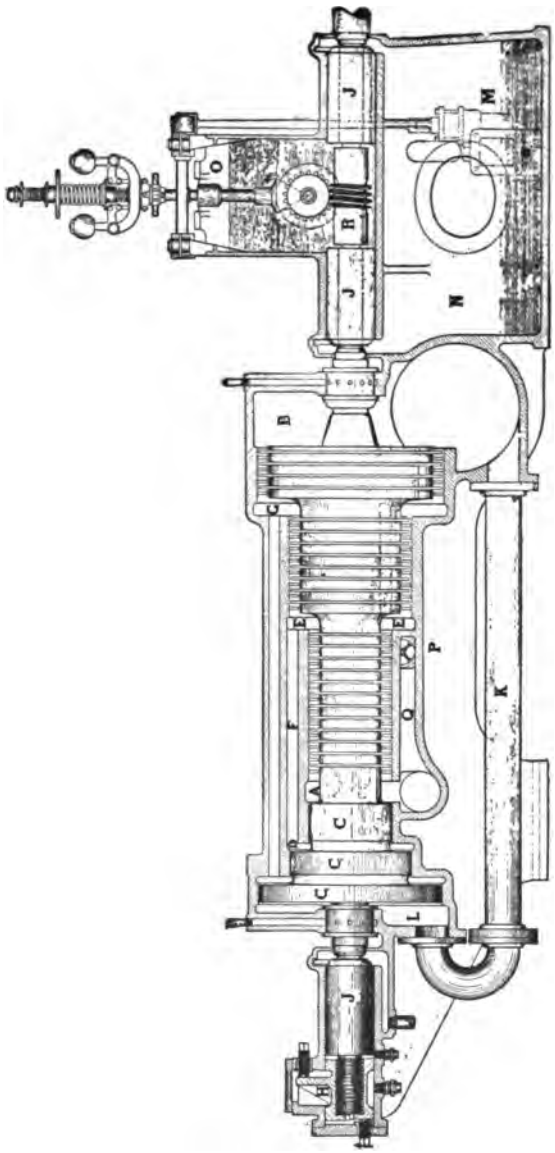


Fig. 52.

Steam is admitted to this turbine in puffs through a reciprocating valve. A fly-ball governor regulates the admission, which is always at boiler pressure.

For electric generators the turbine has many advantages, among them high speed and direct connection. They have small foundations and take up little space; there is slight loss from fric-

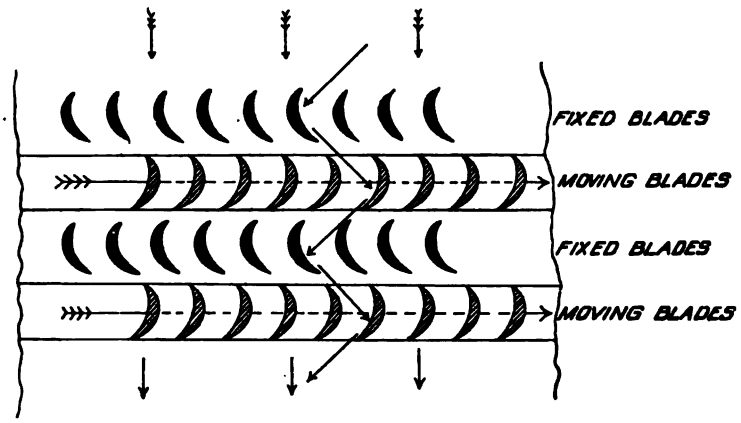
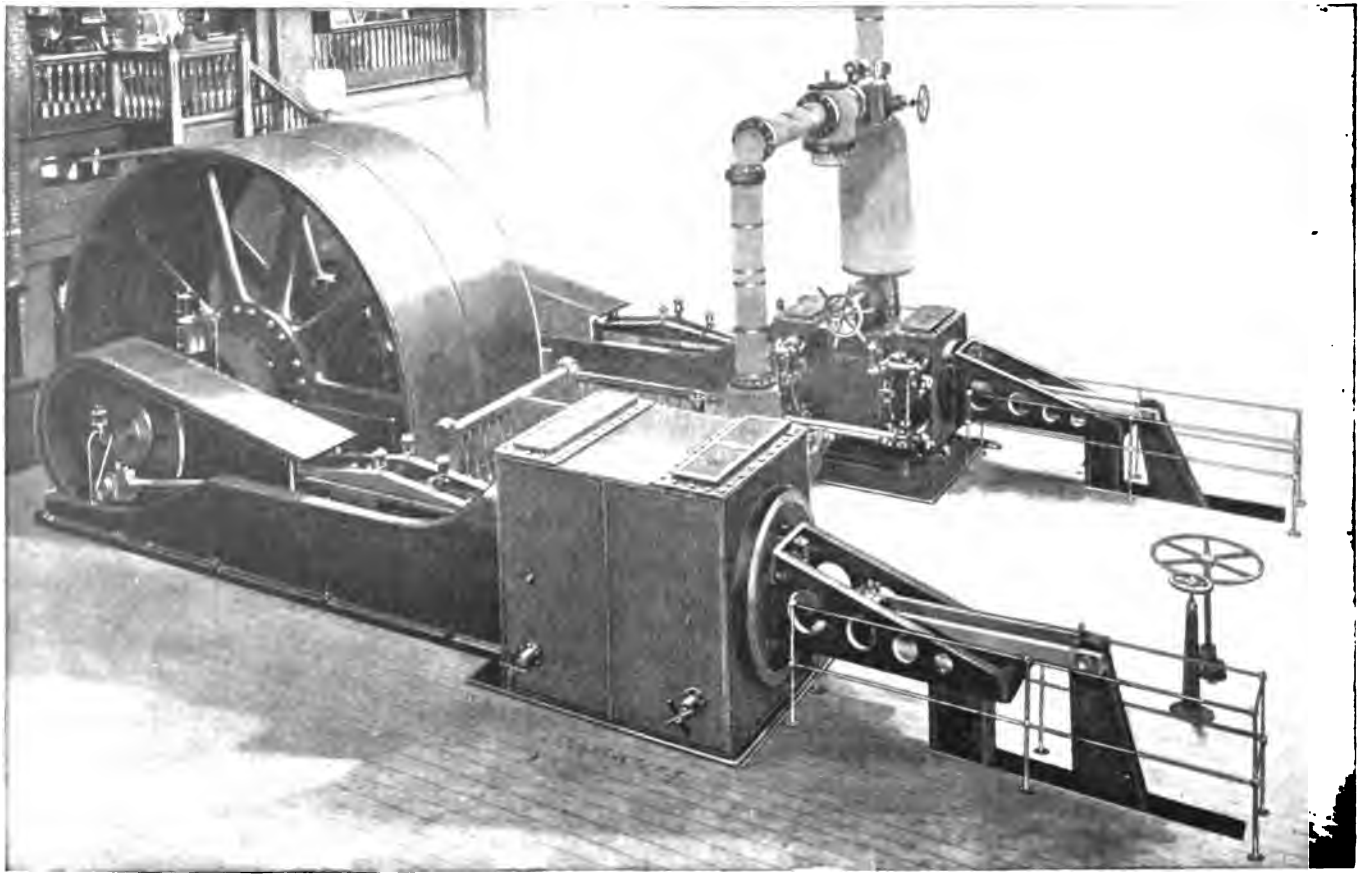


Fig. 58.

tion and few parts. Where slow speed is desired a reciprocating engine is probably the best. The turbines use slightly more steam at present than the best reciprocating engines, but the difference between the two types in matter of steam consumption is growing steadily less. The turbine is an efficient engine, but there is doubtless a chance for further improvement.



1000 HORSE-POWER CROSS-COMPOUND McINTOSH-SEYMOUR ENGINE,
With Direct-connected Air-pump and Air-compressor. Speed, 100 Revolutions per Minute.

SECTION 4.

STEAM ENGINE INDICATORS.

A most important question concerning a steam engine is, "What is its horse-power?" or "How much work will it do in a given time?"

Work is defined as *pressure*, *force*, or *resistance* multiplied by the *distance* through which it acts.

Power is work done in a specified time.

In the steam engine, steam is the agent by means of which heat is transformed into mechanical work. It is the heat in the steam that does the work, not the steam itself.

Work is obtained from the heat in steam by confining it in a closed cylinder which is fitted with a piston and a piston-rod. Steam is admitted at one side of the piston while the other is open to the atmosphere or in communication with a condenser. The pressure of steam, usually 75 to 150 pounds per square inch, forces the piston to the other end of the cylinder, driving out the low-pressure steam in front of it. When it arrives at the other end, steam is admitted to that end and the piston is driven back.

The piston moves because the pressure on one side is greater than that on the other.

In order to move the piston, work must be performed. The amount of work is easily found, since work equals total pressure multiplied by the distance through which the piston moves.

Suppose a piston is 2 square feet in area and steam at a pressure of 64.7 pounds per square inch acts on it during the entire stroke of 4 feet; the other side of the piston being in communication with the atmosphere. The total pressure is then $2 \times 144 \times 64.7 = 18{,}633.6$ pounds. If this pressure acts through 4 feet it is evident from the definition that the work done per stroke will be,

$$18{,}633.6 \times 4 = 74{,}534.4 \text{ foot-pounds.}$$

Another method is as follows: The pressure on the above piston is $64.7 \times 144 = 9316.8$ pounds per square foot. The volume swept by the piston during one stroke is $2 \times 4 = 8$ cubic feet. If we multiply the pressure per square foot by the volume or 9316.8 by 8, we get 74534.4 foot pounds, the same result as before. Thus we see that work equals **unit pressure** multiplied by **volume.**

Let P = pressure on the piston in pounds per square foot.
p = pressure on the piston in pounds per square inch.
A = area of piston in square inches.
L = length of stroke in feet.
V = volume swept by piston in one stroke in cubic feet.
W = work done in foot-pounds.

Then from the above example,

Work = unit pressure multiplied by volume.

or, $W = P \times V$

It is evident that $P = 144\,p$, and $V = \frac{A}{144} \times L$.

Then we have these expressions for work,

$$W = P \times V = 144\,p \times V = 144\,p \times \frac{A}{144} \times L = p\,L\,A.$$

Suppose steam is admitted to the cylinder during the whole stroke, as in the above example, that is, one end of the cylinder is in communication with the boiler. The other end is open to the atmosphere. If we draw two lines at right angles to each other, as O Y and O X in Fig. 1, the volume of steam for any position may be represented by some distance measured on the line O X. Similarly the pressure of the steam at any position of the piston may be represented by the length of a vertical line parallel to the line O Y.

In the above example, the area of the piston was 2 square feet, the length of stroke 4 feet and the pressure by gage 50 pounds. Then we let O A = the atmospheric pressure = 14.7 pounds. At the beginning of the stroke the pressure (absolute) is $14.7 + 50 = 64.7$ pounds, represented by the distance O B, or A B = 50 pounds pressure. When the piston has passed through $\frac{1}{4}$ of the stroke it is represented as the point 1, or B 1 is the volume swept through when the piston has completed $\frac{1}{4}$ of the

stroke. At this point the pressure is also 64.7 pounds as represented at 1′. Similarly, when the piston is at 2, 3, and 4 the corresponding pressure is 2′, 3′, 4′. Since the pressure is constant the line B D is parallel to O X. We see from the above that 50 pounds is the net pressure acting on the piston during the stroke, and is represented by A B and lines parallel to it. The volumes are represented by the horizontal line A C. Then since $W = P \times V$ it also equals O B × O X which is evidently the area of the rectangle O B D X. The area of the rectangle O B D X is proportional to the work done by the steam.

In Fig. 1, one inch on the line O Y = 40 pounds, then O B is 1.6175 inches long since it represents 64.7 pounds. Similarly O A must be .3675 inch since it represents 14.7 pounds. The line A C is 2 inches long; then referring to the preceding example, one inch in length = $\frac{8}{2} = 4$ cubic feet.

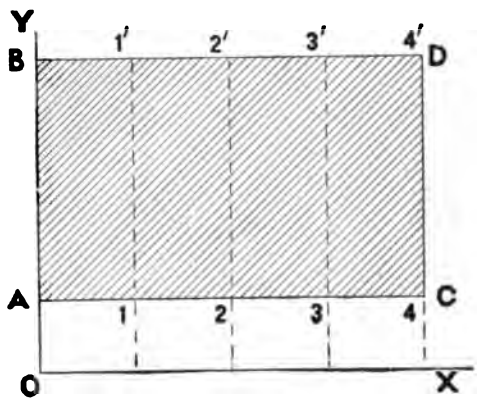


Fig. 1.

Since the rectangle O B D X is 1.6175 by 2 inches, the area is 3.235 square inches. But one inch in height equals 40 pounds pressure and one inch in length equals 2 cubic feet. Then $p\ V = 40 \times 3.235 \times 4 = 517.6$ foot-pounds and,

$W = 144\ p\ V = 517.6 \times 144 = 74{,}534.4$ foot-pounds.

In the above cylinder the pressure acting on one side of the piston was 64.7 pounds per square inch. There was also a pressure of 14.7 pounds per square inch (the atmospheric pressure) acting in the opposite direction. Then the work done against the steam pressure is represented by the area O A C X and is equal to $144\ p\ V = 144 \times 14.7 \times 8 = 16934.4$ foot-pounds. Then since O B D X represents the total work done on one side of the piston and O A C X represents the work done *against* the piston the difference A B D C represents the **net work.** This net work is represented by the shaded area. Also if the amount of work done

on the piston is 74,534.4 foot-pounds and the work done against the piston is 16,934.4 foot-pounds, the net work is the difference, or 57,600 foot-pounds.

In this theoretical discussion the same result may be obtained by subtracting the atmospheric pressure or back pressure from the absolute initial pressure and using the difference as the value of p. This value of p is called the mean effective pressure.

Then $64.7 - 14.7 = 50$ and

$W = 144\ p\ V = 144 \times 50 \times 8 = 57{,}600$ foot-pounds.

The area is proportional to the work done whatever the shape may be; provided the line B D represents the relation between pressures and volumes on the steam side of the piston and the lower line A C represents the relation between pressures and volumes on the exhaust side. If the engine is of the condensing type the line A C will be nearer O X, which is the line representing *absolute vacuum.*

Whatever the shape of the diagram, the area is equal to the area of a rectangle of the same length and a height equal to the mean height, or mean ordinate as it is called. The mean ordinate represents the mean or average net pressure on the steam side of the piston. Then we can follow these rules in finding the work of the steam from the diagram.

Multiply the area in square inches by the scale of pressures, by the scale of volumes and by 144, *or;*

Multiply the length of the mean ordinate by the scale of pressures, by the length of stroke, and this product by the area of the piston in square inches.

Example: The area of a diagram A B D C like that of Fig. 1 is 6.3 square inches and its length is 3 inches. The scale of pressure is 30 pounds per inch and the scale of volumes is 1.99985 cubic feet to the inch. If the piston is 20 inches in diameter and the length of stroke $2\frac{3}{4}$ feet, what is the work done per stroke?

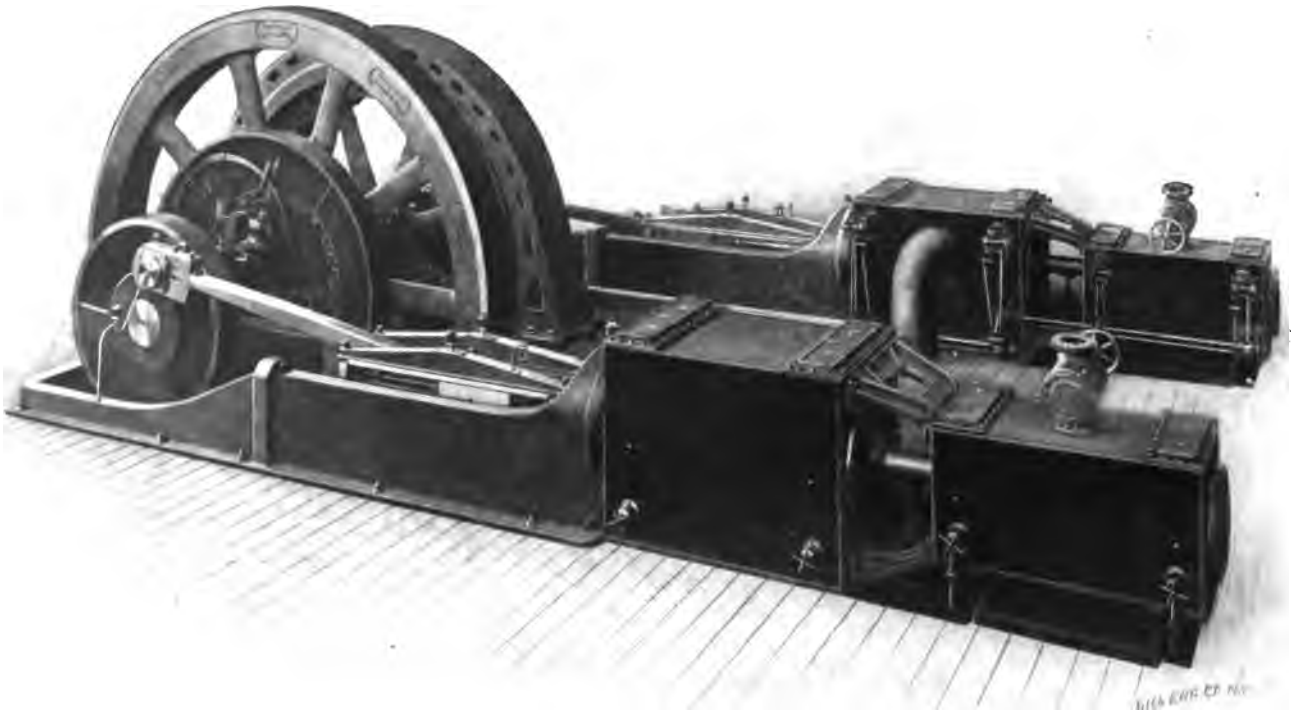
Solution:

W = area of diagram $\times$ scale of pressures $\times$ scale of volumes $\times$ 144.

$= 6.3 \times 30 \times 1.99985 \times 144 = 54{,}428$ foot-pounds.

W = mean ordinate $\times$ scale of pressures $\times$ area of piston $\times$ length of stroke.

$= 2.1 \times 30 \times 314.159 \times 2\frac{3}{4} = 54{,}428$ foot-pounds.



3200 HORSE-POWER DOUBLE TANDEM-COMPOUND ENGINE,
(With a 2000 Kw. Direct-Driven Multiphase Generator.)

Thus we see that we get the same result by both rules. The latter is the more common method because the mean ordinate is easily found and the scale of volumes seldom considered.

In our consideration of Fig. 1, steam was admitted to the cylinder during the *entire stroke*. In modern engines this method is rarely used; instead, steam is admitted during *part* of the stroke then the communication to the boiler is cut off, and the steam in the cylinder allowed to **expand**, as the piston moves forward, until it fills the entire volume of the cylinder. This is represented graphically in Fig. 2.

Steam is admitted to the cylinder until the piston reaches the point 2 which represents one-half the volume of the cylinder. Then the cylinder is half full of steam, that is, it contains $\frac{8}{2} = 4$ cubic feet. The four cubic feet of steam expand until they fill the cylinder. Since there is the same weight of steam present at every point in the stroke and the volume continued to increase, the pressure must diminish. This is shown in Fig. 2. The line B 2′ is horizontal because the pressure remains constant to the point of cut off. Then the pressure begins to fall as is represented by the curved line 2′ E. This curve is nearly an equilateral hyperbola.

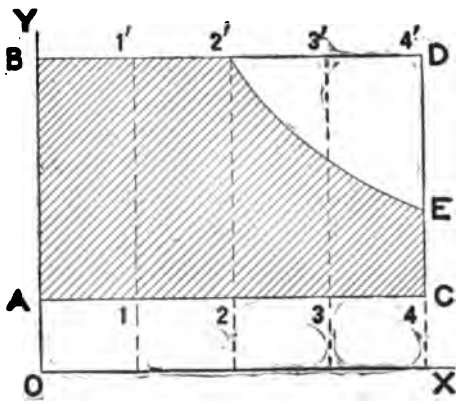


Fig. 2.

From Fig, 1 we know that the area B 2′ 2 A is proportional to the work done while the piston moves from A to 2 or during the first half of the stroke. If we use the same data as we did in Fig. 1, the work done must be one-half the work done in the first case, or $\frac{57600}{2} = 28800$ foot-pounds. Also the area B 2′ 2 A is easily found since it is a rectangle. The area 2′ E C 2 is found by dividing it up into small sections, by calculus or by the use of a planimeter.

It is easily seen that the area of the second case Fig. 2, is less than that of Fig. 1. Therefore the work done is less; but the amount of steam admitted is only one-half as much as in the first case.

In the first case, Fig. 1, 8 cubic feet of steam at 50 pounds pressure were admitted per stroke and the work done was found to be 57600 foot-pounds. In the second case only half as much steam is admitted and the work done is $\frac{57600}{2}$ + the amount represented by the area 2′ E C 2. Thus we see that there is a considerable gain by expanding the steam.

Watt's Diagram of Work. Fig. 3 illustrates the method adopted by James Watt to show the action of steam in the cylin-

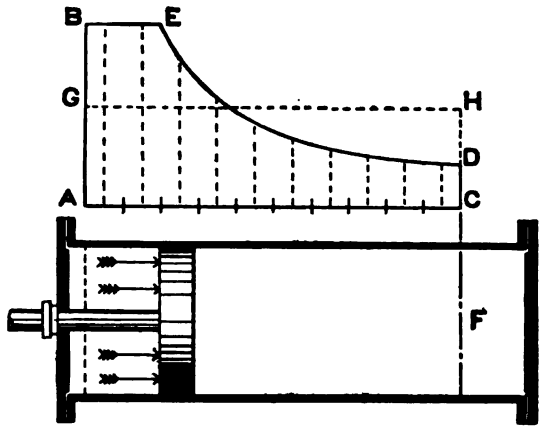


Fig. 3.

der. The horizontal line A C called the abscissa represents the length of the stroke and is divided into ten equal parts. The vertical line A B called the ordinate indicates the pressure of steam.

When the piston has moved to the point E steam is cut off, that is, a volume of steam equal to $\frac{1}{5}$ the volume of the cylinder expands until it fills the entire cylinder. The area may be found by adding the several pressures (shown by the dotted lines), dividing by the number of divisions, and multiplying by the length.

If by some arrangement of steam tight pistons working in cylinders and having pencils fastened to them, we could get a dia-

gram like that shown in Fig. 3 it would be of great use but too large for convenience.

To obtain the same diagram on a small scale an indicator is used. The value of such a diagram has already been shown when finding the work done in the cylinder. The indicator has enabled engineers to bring the engine of today to its present state of excellence. A correct idea of the action of steam in the cylinder can be obtained only by means of an indicator. It shows whether or not the valves are set properly and how the condenser is working. It also shows the engineer which end of the cylinder is doing the most work. By comparing the expansion line with an equilateral hyperbola, with a curve of constant steam weight, or with an adiabatic curve for steam, the cylinder condensation is calculated.

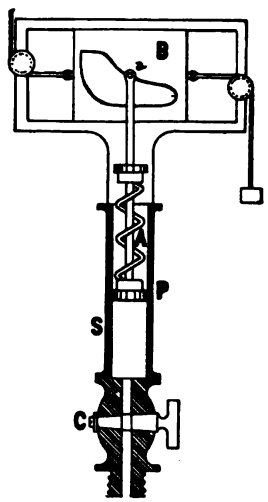


Fig. 4.

James Watt was the first to see the need of accurate knowledge of the action of steam in the cylinder. He invented the indicator. The improved form consisted of a steam cylinder S, about one inch in diameter and six inches long, in which a solid piston P, is accurately fitted. A spiral spring A, is attached to this piston, and controls the motion of a pencil *a*, which is also attached to the piston. This pencil can operate on a sheet of paper fastened to a sliding board, B. This board moves back and forth by means of a weight at one end and a cord at the other which is connected to some reciprocating part of the engine. The indicator cylinder S, may be put in communication with the engine cylinder by means of the cock C. With this instrument a complete diagram can be taken.

Watt's first indicator had no lateral motion, therefore all it showed was the pressure of steam in the cylinder and the perfection of the vacuum.

INDICATORS.

The diagram, or card as it is often called, obtained by the use of an indicator is the result of two motions. The *horizontal* move-

ment of the paper corresponds exactly to the movement of the piston, and the *vertical* movement of the pencil is an exact ratio to that of the pressure of steam in the cylinder. The diagram represents by its *length* the stroke of the engine and by its *height* the steam pressure on the piston at the corresponding point of the stroke. The diagram shows the action of steam on one side of the piston only; to obtain the same information in regard to the other side it is necessary to take another diagram from the other end of the cylinder.

The essential features of an indicator are found in the instrument invented by James Watt. Since his time, however, the many improvements have made the indicator light, compact, durable, and accurate. Watt's diagram was traced on paper stretched on a sliding board but now a revolving drum is used. The height also of Watt's diagram was equal to the movement of the spring, and the pencil arrangement was a simple contrivance. In the indicators of the present day, the spring has a slight movement, the height of the card being obtained by a multiplying arrangement of levers. This method requires a parallel motion to obtain accuracy in the vertical lines; for if a lever is pivoted at one end and power applied near the pivot the lever tends to rise and the free end will describe an arc of a circle, not a straight vertical line.

THE THOMPSON INDICATOR.

Two views of the American Thompson Indicator, the outside and the inside, are shown in Figs. 5 and 6. The form of spring is shown in Fig. 7. The indicator consists of a cylinder in which a piston is fitted, a spring, multiplying lever and parallel motion for the pencil and a cylinder or drum for the paper. The piston, which is .798 inch in diameter = $\frac{1}{2}$ square inch in area, is fitted accurately to the cylinder and has a travel of about one-half inch. When the pressure of steam forces the piston upward it compresses the spring above it; the amount of compression varies with the strength of the spring. The rise of the piston causes the pencil to rise because of the system of levers. The cylinder to which the paper is attached rotates by means of a cord which is fastened to some part of the engine, the crosshead for example.

While the drum revolves and the steam pressure forces the piston to rise, the pencil, lightly touching the paper, decribes the diagram.

The parallel movement of this indicator is obtained by a link attached directly to the lever. It is so constructed that there is but little lost motion, hardly any friction and no appreciable error within the limited movement of the pencil.

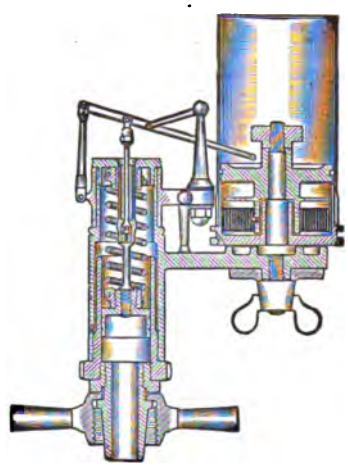


Fig. 5.

The paper cylinder is so constructed that the tension of the coiled spring within the drum may be altered for different speeds of the engine. By this means the cord can be kept taut with little trouble. The cord is led through a hole and kept in contact with the scored wheel by another small one. By this means the cord can be run to any angle. It is convenient to have the cards of about the same size. If we used a spring of such a tension that the pencil would move one inch for every 60 pounds pressure, and there was but 30 pounds pressure in the engine cylinder, the diagram would be but one-half inch high. This diagram would be too small for accurate work. For this reason indicators are provided with sets of springs of varying stiffness which may be used according to the steam pressure. If a spring is of such stiffness that the pencil moves 1 inch for every 40 pounds pressure it is called a 40 pound spring. Others are called 10 pound, 20 pound, 30 pound, etc., springs.

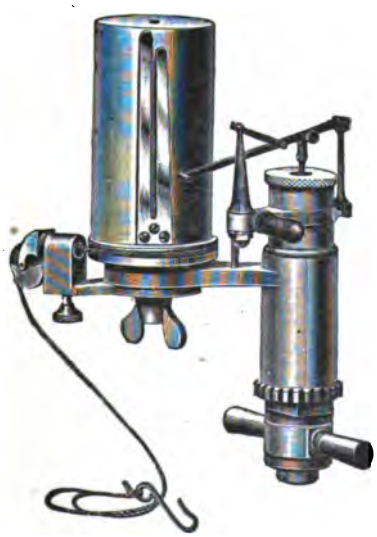


Fig 6.

To Change the Springs. In selecting the spring for a given pressure, care should be taken that it will easily stand that press-

ure. A safe rule to follow: multiply the scale of the spring by $2\frac{1}{2}$ and subtract 15 for the vacuum.

For example: The maximum pressure for a 50 pound spring is 110 pounds, because $(50 \times 2\frac{1}{2}) - 15 = 125 - 15 = 110$. Springs are made in the following scale: 8, 10, 12, 16, 20, 24, 30, 32, 40, 48, 50, 56, 60, 64, 80, 100. For pressures from 70 to 90 pounds a 40* pound spring should be used, as 80 pounds pressure on a 40 pound spring will raise the pencil 2 inches, and this is a good height for the diagram.

If very high pressures are to be indicated, an extra piston, having an area of $\frac{1}{4}$ square inch, is used. This doubles the allowable pressure on the spring. For instance, if as pring can be used for 110 pounds pressure when the piston is $\frac{1}{2}$ inch in area, it can be used for 220 pounds pressure if the $\frac{1}{4}$ inch piston is used.

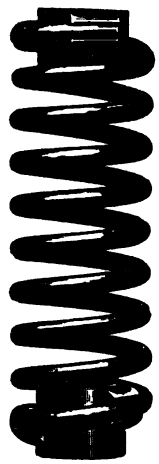


Fig. 7.

When the spring has been selected it is placed in the indicator. First unscrew the milled nut at the top of the steam cylinder and take out the piston with arm and connections. The pencil lever and piston are disconnected by unscrewing the small-headed screw which connects them. If a spring is connected to the piston it should be removed, the selected one substituted and the indicator put together. The spring should always be firmly screwed to the shoulder or the pencil will not properly indicate the pressure.

Care of the Indicator. Before attaching the indicator to the engine cylinder it should be taken apart, cleaned and oiled. If each part works freely and smoothly the spring may be put in and the indicator put together. After connecting to the cylinder, admit steam to it, but do not take cards until it is thoroughly warmed and blows dry steam through the relief. It is not necessary to use lead in connecting as it is likely to get into the indicator. After using, take the indicator apart, clean and oil. Only porpoise or fine watch oil should be used.

THE CROSBY INDICATOR.

The internal arrangement of the parts of the Crosby Indicator

* NOTE: In practice it is better to use a somewhat stiffer spring.

is shown in Fig. 8. The piston, 8, is formed with shallow channels on its outer surface to retain oil which prevents leakage and lubricates the piston.

The socket in the center of the piston is supported by a central web and projects both upward and downward. The upper

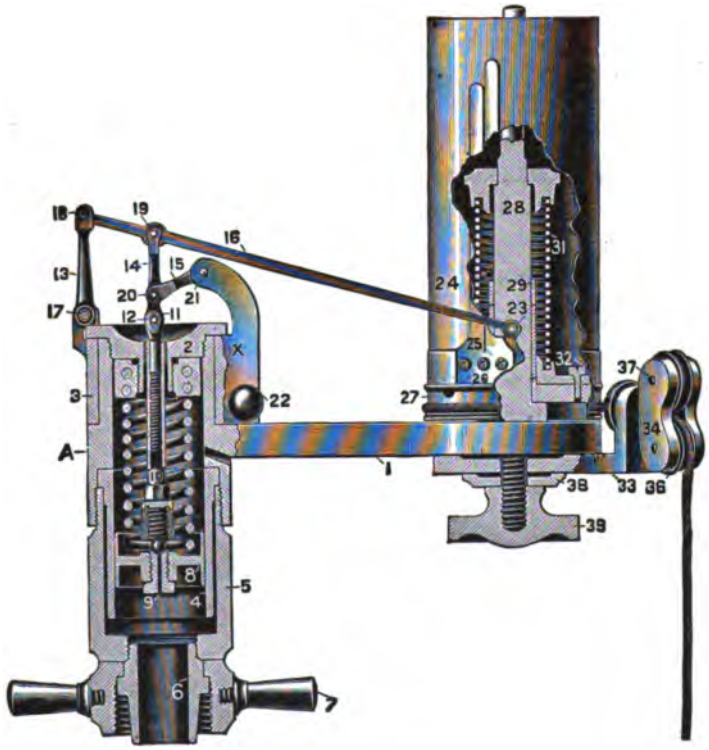


Fig. 8.

portion is threaded inside to receive the lower end of the piston-rod. It has a vertical slot which allows the ball bearing on the end of the spring to drop into a concave bearing on the upper end of the piston-screw, 9, which is screwed into the lower part of the socket.

The piston-rod, 10, is made hollow, with the lower end threaded. When the piston-rod is connected to the socket, the former should be screwed into the socket as far as it will go.

The height of the atmospheric line on the diagram depends

upon the amount the swivel head, 11, is screwed into the top of the piston-rod.

A small projection on the lower side of this cap is threaded to screw into the top of the spring and hold it firmly in place. The moving parts are kept in line by this cap. The pencil mechanism is supported by the sleeve 3, which surrounds the upper part of the cylinder; it turns freely and is held in position by the cap.

The pencil mechanism is made as light as is consistent with strength and stiffness. The pencil moves exactly parallel to the piston because the fulcrum of the mechanism and the point of attachment to the piston-rod are always in a straight line. The pencil point moves six times as far as the piston because of the multiplying levers.

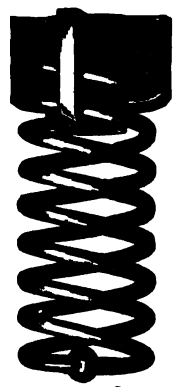


Fig. 9.

The drum 24, is one and one-half inches in diameter, and is rewound when the string is pulled, by a short spiral spring 31.

The piston spring is made of a single piece of steel wire wound from the middle into a double coil. The ends are screwed into a brass head having four radial wings. At the bottom of the spring a small steel bead is firmly attached to the wire. This forms a ball and socket joint with the lower end of the piston-rod. This joint is light and allows the spring to yield to pressure from any direction. These springs are made in the following scale: 8, 12, 16, 20, 24, 30, 40, 50, 60, 80, 100, 120, 150, and 180.

To Insert the Spring. First unscrew the cap 2, then lift the connected parts free from the cylinder by means of the sleeve. The hollow wrench should be held in an inverted position and the piston-rod inserted until the hexagonal part engages the wrench. Then, having the spring shown in Fig. 9 inverted, insert the combined wrench and piston-rod until the steel bead and the end of the spring rests in the concave seat. Now invert the piston and pass the transverse wire at the bottom of the spring through the slot until the threads at the bottom of the piston-rod engage those inside the socket of the piston. With the wrench screw it in as far as it will go.

The piston screw should be loosened slightly before the piston-rod is screwed in, and afterward set up against the bead lightly to prevent lost motion. Then with the sleeve and cap upright, engage the threads of the swivel bead with those inside the piston-rod and screw it up until the lower projection of the cap engages the threads inside the spring top; continue the process until the spring is screwed up firmly against the cap. Holding only by the sleeve 3, turn the piston and the connections until the top of the piston-rod is flush with the shoulder on the swivel head.

Now that the piston and all the connections are in their places, the whole may be inserted in the cylinder and the cap screwed down, which will fix all parts in their proper places. If there is a spring in the cylinder first detach by reversing the above process.

THE TABOR INDICATOR.

The Tabor Indicator is shown in Fig. 10. It is used extensively in the navy. The principle of action and details of construction are similar to the indicators already described; the chief peculiarity being the means employed to obtain a straight line movement for the pencil. Inside the steam cylinder is a lining in which the piston moves. This lining can expand when heated. In the side of the cylinder small holes allow any steam which may leak by the piston to escape. The piston-rod is connected at one end to the piston by means of a ball and socket joint; the other end is connected to the pencil mechanism.

The **pencil mechanism** consists of three pieces, the pencil lever, the back link, and the piston-rod link. The two links are parallel for every position of the pencil. Thus the lower pivots of these links and the pencil point are always in the same straight line. The straight line movement of the pencil is obtained by means of a curved slot in a stationary plate. The pencil bar is provided with a roller which is fitted in such a manner that it can roll from one end of the slot to the other. The curve of the slot guides the pencil bar and is of such a radius that the pencil is caused to move in a straight line. The curve compensates for the tendency of the pencil point to move in an arc of a circle. The

pressure of the pencil on the paper is regulated by a screw which strikes a stop plate attached to the frame. The end of the pencil bar is formed for either a pencil lead or a metallic marking point.

The drum for the paper is made similar to those of other indicators. The backward movement is obtained by a flat spiral spring placed under the drum. The tension of this spring is altered by loosening a thumbscrew, lifting the carriage, and winding or unwinding. A simple pulley guides the driving cord in any direction.

Fig. 10.

The indicator is attached by a coupling having a single thread.

The **springs** of the Tabor indicator are of the duplex type, that is, they are made of two spiral coils of wire. A 50 pound spring is shown in Fig. 11. The wire terminates in fittings at each end. The spring is attached to the upper side of the piston by means of threads cut on the inside of the fitting and on a projection on the piston. The top of the spring is attached to the under side of the cover in a similar manner. The springs are made in the following scales, 8, 10, 12, 16, 20, 24, 30, 32, 40, 48, 50, 60, 64, 80, and 100 pounds. The maximum safe steam pressures (absolute) to which these springs may be subjected are respectively, 10, 15, 20, 24, 40, 48, 70, 75, 95, 112, 120, 140, 152, 180, and 200 pounds.

Change of Location of Atmospheric Line. Unscrew the cap and lift the sleeve and connections from the cylinder. Then turn the piston to the left or right according as the pencil is to be raised or lowered. One revolution causes the pencil to rise $\frac{1}{8}$ inch.

Care of the Indicator. Before attaching the indicator to the engine, steam should be blown through the pipes and cocks so that all particles of dust may be removed. After using, the indicator should be carefully wiped and oiled. The cylinder cap should be unscrewed and all the parts connected to the piston removed. The piston spring and piston-rod should be detached, carefully wiped dry, and then oiled. The inside of the cylinder also should be oiled. Then the piston and piston-rod should be placed in the cylinder and the spring placed in the box. If the indicator has not been used for some time the oil may have become gummed. It may be easily cleaned by wiping with a cloth saturated with naphtha or benzine. It must be oiled again before using. A good test that the indicator is in proper working order is to detach the spring and after replacing the piston and piston-rod, raise the pencil to the highest point. When allowed to fall it should descend to the lowest point freely. The pencil should always have a smooth fine point.

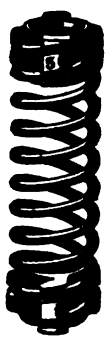


Fig. 11.

To Attach the Indicator to the Engine. Usually all first-class engines are prepared for the indicator before leaving the factory. Holes are drilled and tapped in the cylinder and have plugs screwed in them. These plugs are easily removed and the indicator connections screwed in.

When this is not the case, any engineer can perform the work. Before drilling the holes, in the cylinder, the heads should be removed so that the exact positions of the pistons and the size of the ports and passages may be known. Also with the heads off all chips and particles of dirt from drilling may be easily removed. If it is impossible to remove the heads, a little steam admitted to the cylinder just before the drilling is completed will blow the chips out.

Each end should be drilled and tapped for a one-half inch pipe thread. The holes must be drilled into the clearance space, so that the piston at the ends of the stroke will not cover them. They should also be placed so that currents of steam will not reach them. Before deciding just the points at which to drill the holes, it is well to consider every plan of indicating the engine. The type of engine, the position of the steam chest, the kind of cross-

head, and the position of the eccentric and its connections should all be considered, as well as the most convenient place in the engine room. The holes should not be drilled until the plan shows the proper connections with the reducing motion, convenient access and free passage of steam to the indicator.

When the plan has been adopted, the engine should be placed on dead center, to determine the clearance. The holes should be drilled into the middle of the clearance space.

In common practice for horizontal engines the holes are drilled in the side of the cylinder at each end. Short half inch pipes with quarter upward bends into which the indicator coils may be screwed are inserted in these holes.

It may be more convenient to drill and tap into the top of the cylinder and attach the indicators directly.

For vertical engines, the upper head or cover and the side of the cylinder are often drilled and tapped for the upper and lower indicators respectively. It is preferable to connect the indicators

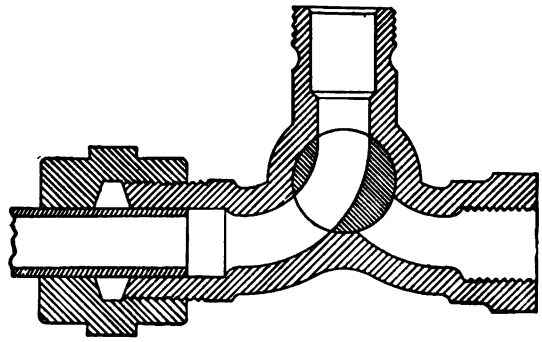


Fig. 12.

to the sides because less pipe and fittings are required and better results obtained.

If only one indicator is to be used for both ends of the cylinder, it may be connected by side pipes and a **three way cock.** By this method both diagrams are taken on the same card and with the loss of but one revolution. Fig. 12 shows the section of a three way cock.

Reducing Motion. As we have already seen the length of the card represents the travel of the piston. As the length of

card is obtained by the rotation of the drum the motion of the drum must be taken from some part of the engine which has a motion coinciding with that of the piston. The crosshead is the most common, reliable and convenient part. The length of the card is much less than the travel of the piston since the stroke is longer than the circumference of the drum so that the movement of the crosshead must be reduced to the length of the diagram.

There are several devices employed to obtain this reduced motion.

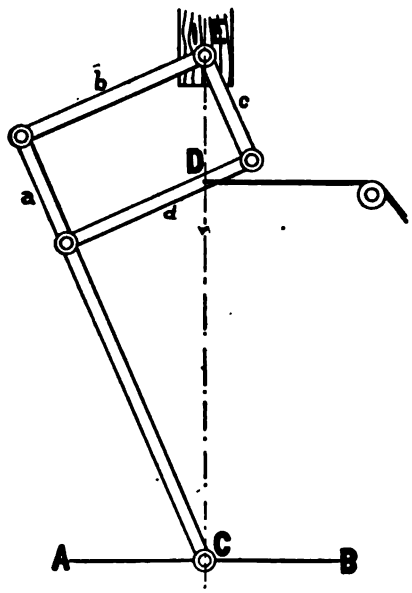


Fig. 13.

A simple form of reducing motion, called the **pantograph**, is shown in Fig. 13. Four links, *a*, *b*, *c*, *d*, are joined in the form of a parallelogram. One link, *a*, is prolonged and pivoted at the crosshead C. The point where *b* and *c* join is pivoted at the fixed point E. The cord is fastened at D on the link *d*. The point D must be in the straight line connecting E and C. Then letting A B represent the stroke and *h* the length of the indicator diagram, we have

$$A\,B : h = E\,C : E\,D, \text{ from which}$$

$$E\,D = \frac{h \times E\,C}{A\,B}$$

Another form of pantograph is shown in Fig. 14. It is placed horizontally with the pivot, B, resting on a support opposite the crosshead when in mid-position. The pivot A, is attached to the crosshead; usually by having the stud A inserted in a hole drilled in the crosshead. If the pivot B is adjusted to the proper height and at the right distance from the crosshead, the cord from the indicator may be attached to the pin E without any pulleys. The

length of the diagram is varied by adjusting the movable bar C D; the pin E must be in the straight line from A to B.

The pantograph is likely to become shaky and loose on account of its many joints. If well made it gives perfect motion.

The reducing motion shown in Fig. 15, called the Brumbo Pulley, is easily and quickly made and can be used on almost any engine. The wooden rod A is usually about twice as long as the stroke. It is pivoted by a bolt or screw at B, a fixed point. At the lower end it is connected by the wooden link, C, to the crosshead.

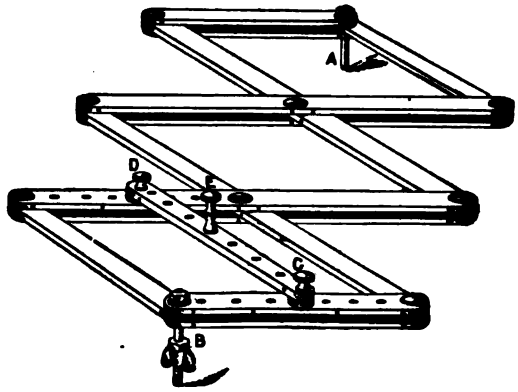


Fig. 14.

This link C is usually about one-half the length of the stroke. The sector S may be made either of wood or metal. It should have a groove in the circular edge for the cord, and is made fast to the upper end of the lever A. Its center should coincide with that of the pivot B. The length of the radius of the sector may be found as follows. Divide the length of the lever by the length of the stroke, multiply the result by the length of the desired diagram and the product will be the radius of the sector. For instance, if the lever is 60 inches long and the stroke 30 inches and we wish the diagram to be 3 inches long, the sector should be 6 inches in radius for,

$$\frac{60}{30} \times 3 = 6.$$

To avoid the use of guide pulleys the lever should be hung so that it will swing in a vertical plane parallel with the guides and in line with the indicator. When the crosshead is at mid-stroke,

the lever must be vertical and the point D must be below the axis of the cylinder because it comes above the line at the ends of the stroke.

The reducing lever used for large quick running engines is shown in Fig. 16. The rod A is made of pine wood, tapering toward the lower point and about one inch in thickness. The length is about one and one-half times the length of the stroke. It is suspended by a bolt or screw from some fixed point above the engine, and should swing edgewise and parallel to the guides of the crosshead. The steel stud at the bottom of the rod has a T shaped slot in an iron plate which is attached firmly to the crosshead. The slot should be long enough to retain the stud when the crosshead is at the end of the stroke. To find the point at which the indicator cord should be attached, divide the length of

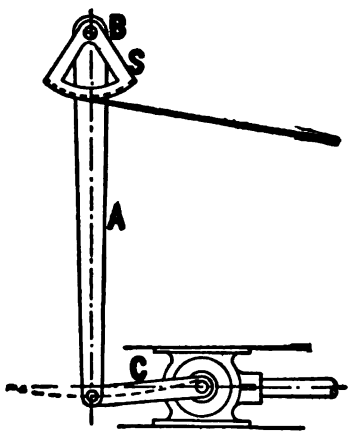


Fig. 15.

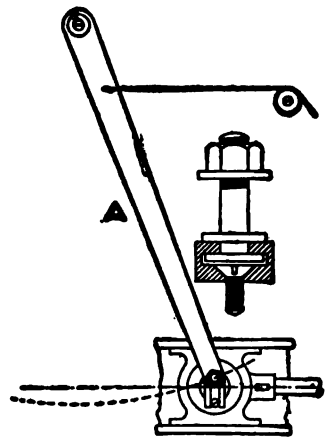


Fig. 16.

the lever by the length of the stroke of the piston and multiply the quotient by the length of the desired diagram. The product is the distance of the point from the pivot at the top of the lever.

Example. A lever is 45 inches long, the piston stroke 30 inches and the diagram to be $3\frac{1}{4}$ inches long. At what distance from the pivot should the indicator cord be attached?

$$\frac{45}{30} \times 3\tfrac{1}{4} = 4\tfrac{7}{8} \text{ inches.}$$

Having placed the indicator in position and obtained the

reducing motion, the length of the cord must be so adjusted that the drum will not strike the stops at either end of the stroke.

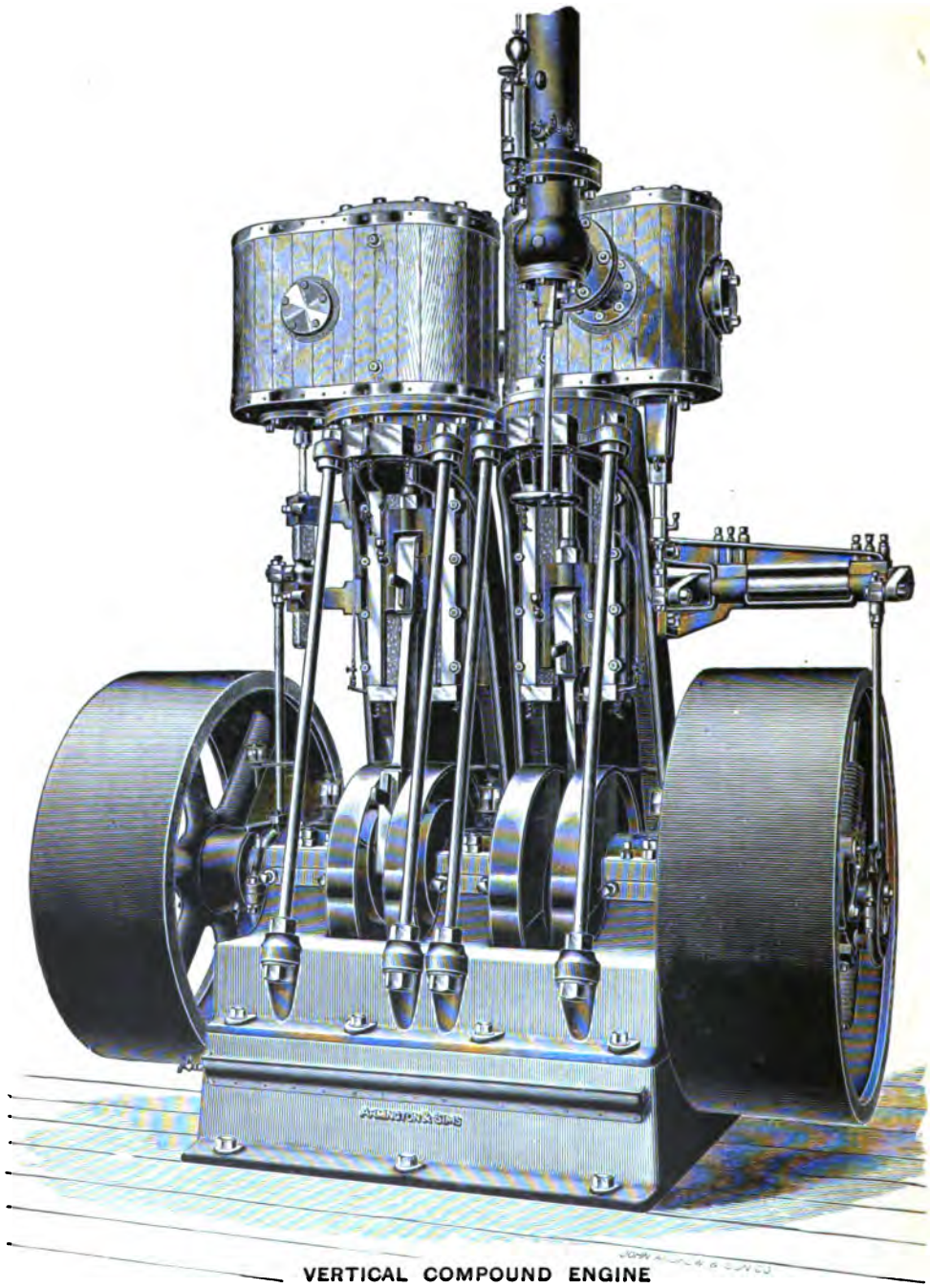
For convenience an approximate length of cord is first found and the cord cut in two parts, one attached to the reducing motion; the other to the indicator. A hook should be fastened to the free end of the piece attached to the indicator. A loop is made in the free end of the piece from the reducing motion. The hook is then attached to the loop and the extra length of cord taken up by tying knots. Another method for adjusting the length of the cord is the arrangement shown in Fig. 17. The hook A is attached to the indicator cord. The cord B from the reducing motion passes through the holes in the plate P as shown. To adjust the length of the cord it is slacked at the point B and the plate slipped along the cord.

Fig. 17.

To Take Indicator Diagrams. The indicator should be in good working order before attaching to the cylinder; it should be clean, well oiled, and the levers and springs should work smoothly. The pencil point should be sharp and the pressure adjusted to make a distinct fine line.

The spring should be selected that will give a diagram $1\frac{1}{2}$ to 2 inches in height. If the spring chosen is too light, the lines are likely to be wavy from the vibration of the pencil levers.

When the indicator is in position a satisfactory reducing motion obtained and the cord adjusted, the paper should be wrapped smoothly around the drum. The edges projecting over the clips should be folded back so that they will not touch the pencil lever. Before taking the card, allow the steam to enter the indicator and move the piston up and down until the parts have become thoroughly warmed. Then pass the pencil against the paper long enough to take the diagram. Some engineers allow the pencil to remain in contact with the paper during but one revolution of the engine; others trace the diagram two or



VERTICAL COMPOUND ENGINE

more times. After the diagram is taken the cock is shut and without unhooking the cord the pencil is again pressed to the paper to take the atmospheric line. The cord is then disconnected and the card removed from the drum. The scale of spring, the dimensions and speed of the engine, the date, and all useful particulars are written on the cards.

If one indicator is used for both ends the three way cock shown in Fig. 12 is opened to admit steam from one end, the diagram taken; then opened for the other end and that diagram taken. Then the steam is shut off from both ends and the atmospheric line taken.

As has been said before, the indicator is of great importance to the engineer. It is used to find the indicated horse-power of the engine, and by comparison of the indicated horse-power with the brake horse-power, the **mechanical efficiency** is obtained. The indicator card shows several other things; the *time* and *manner* of the **four events** of the stroke, namely, the admission, cut-off, release, and compression. These four events make up what is called the **steam distribution.** It shows faults in the setting and working of the valves.

We have seen how the indicator diagram represents the net work done on the piston in one stroke.

Work is equal to pressure multiplied by the distance through which it acts. The *distance* is the length of stroke multiplied by the number of strokes per minute. The *pressure* is the *average net* pressure acting on the piston during the stroke. This average net pressure is called the **mean effective pressure.** If we know from the indicator card the mean effective pressure per square inch, we can find the total pressure by multiplying it by the area of the piston in square inches.

The distance per minute is equal to the length of stroke multiplied by the number of strokes.

Let P = mean effective pressure in pounds per square inch.

A = area of piston in square inches.

L = length of stroke in feet.

N = number of strokes per minute.

Then the work done per minute,

$$W = P\,L\,A\,N.$$

Since one horse-power is the rate of doing work when 33,000 foot-pounds of work are done per minute the **indicated horse-power** of an engine is obtained by means of the formula,

$$\text{H. P.} = \frac{\text{P L A N}}{33{,}000}$$

The length of the stroke, the area of the piston and the number of strokes are easily found. Then all that remains to be determined before the horse-power is calculated is the value of P, or the mean effective pressure.

Suppose one side of the piston is in communication with the boiler during the entire stroke, the mean pressure is then the boiler pressure. But if the supply of steam is cut off before the stroke is completed, the mean pressure will not equal the boiler pressure. In Fig. 1 we saw that the area of the shaded portion was equal to the length multiplied by the height. The area of a figure of any shape can be reduced to that of a rectangle having a length equal to the extreme length of the figure. Then whenever we know the area and length, we can find the height or mean height by dividing the area by the length.

Suppose a diagram like that shown in Fig. 2 has an area of $5\frac{1}{4}$ square inches and its extreme length is $3\frac{1}{2}$ inches; then the height is 5.25 divided by 3.5 = 1.5 inches. Then with any indicator card the area of the diagram is equal to the area of a rectangle, the length of which is known and the height can easily be computed.

Suppose that we have taken a card and know that the mean height is $1\frac{1}{2}$ inches. In order to find the horse-power we must reduce the $1\frac{1}{2}$ inches to pounds pressure. If we multiply the height by the strength of the spring we get the desired result. For instance, if we had used a 30 pound spring (that is one which causes the pencil of the indicator to move one inch for every 30 pounds pressure in the cylinder) the height $1\frac{1}{2}$ inches would equal $30 \times 1\frac{1}{2} = 45$ pounds pressure.

Example. An indicator card has an area of 1.925 square inches and is 2.2 inches long. If a 60 pound spring is used what is the mean pressure?

The mean height equals $\frac{1.925}{2.2} = .875$ inch and

$$.875 \times 60 = 52.5 \text{ pounds.}$$

Suppose the engine from which the above card was taken had a piston 14 inches in diameter and a stroke of 24 inches. If it were running at 150 revolutions per minnte what is its horse-power? Assume the mean effective pressure to be the same for both sides of the piston.

$$\text{H. P.} = \frac{\text{P L A N}}{33{,}000}$$

$$= \frac{52.5 \times 2 \times 153.94 \times 300}{33{,}000}$$

$$= 147. \quad \text{(about)}$$

In most engines more work is done at one end of the cylinder that at the other; it is not safe then to assume the mean effective pressure of one side the same as that of the other. Cards should be taken from each end and calculated for mean effective pressure separately, then averaged. Also the area of one side of the piston is greater than the other on account of the piston-rod. The two ends may be figured separately or the average area of the two sides of the piston may be used as the value of A.

Another method is to find the work done at each end of the cylinder and then add the results. This enables the engineer to know if his valves are set so that each end does about the same amount of work.

An engine has the following dimensions. The piston is 12 inches in diameter, the piston-rod is $2\frac{1}{8}$ inches in diameter and the length of stroke is 34 inches. While running at 92 revolutions cards were taken. The area of the card from the head end was 5.36 square inches, that of the crank end was 5.30 square inches, and a 40 pound spring was used. The cards were 3.72 inches long. We wish to know what horse-power the engine developed and which end was doing the most work.

The area of the piston is 113.097 square inches for the head end and 113.097 — 3.5466 = 109.55 square inches for the crank end.

Then for the head end,

$$\text{H. P.} = \frac{\text{P L A N}}{33{,}000} = \frac{\text{P} \times 34 \times 113.097 \times 92}{12 \times 33{,}000} = .8933\ \text{P}$$

and for the crank end,

$$\text{H. P.} = \frac{\text{P L A N}}{33{,}000} = \frac{\text{P} \times 34 \times 109.55 \times 92}{12 \times 33{,}000} = .8653\ \text{P}$$

The value of P is found from the cards. Since the cards were 3.72 inches long and the area of the card from the head end was 5.36 square inches the mean ordinate is $\frac{5.36}{3.72} = 1.44$ inches which equals $1.44 \times 40 = 57.6$ pounds. The horse-power would be,

$$.8933 \times 57.6 = 51.45$$

For the crank end the mean effective pressure is found as before,

$$\frac{5.30}{3.72} = 1.425 \text{ and } 1.425 \times 40 = 57.$$

The horse-power would be,

$$.8653 \times 57 = 49.32$$

The horse-power is evidently the sum of these two quantities or $51.45 + 49.32 = 100.77$.

The head end is doing more work than the crank end but the difference is slight being only,

$$51.45 - 49.32 = 2.13 \text{ horse-power,}$$

or about 2.1 per cent. of the total power.

Considerable arithmetical work is necessary when the I. H. P. is found from the formula,

$$\text{I. H. P.} = \frac{\text{PLAN}}{33{,}000}$$

and the chances for error are of course, great. To save time and reduce the chance for error a table of engine constants has been prepared. The number of strokes, or twice the number of revolutions, multiplied by the length of stroke in feet is called the **piston speed.** Then in the formula $\text{I. H. P.} = \frac{\text{PLAN}}{33{,}000}$, $\text{L N} =$ piston speed in feet per minute. In the following table, the I. H. P. of an engine is easily computed by multiplying the constant, corresponding to the diameter of the piston, by the piston speed and by the M. E. P. Or, in other words, the constants in the table equal the horse-power for an engine with a given diameter of piston having a piston speed of one foot per minute and a M. E. P. of one pound.

TABLE OF ENGINE CONSTANTS.

Diameter of Cylinder.	Even Inches.	+ 1/8 or .125.	+ 1/4 or .25.	+ 3/8 or .375.	+ 1/2 or .5.	+ 5/8 or .625.	+ 3/4 or .75.	+ 7/8 or .875.
1	.0000288	.0000801	.0000872	.0000450	.0000535	.0000628	.0000729	.0000837
2	.0000952	.0001074	.0001205	.0001342	.0001487	.0001640	.0001800	.0001967
3	.0002142	.0002324	.0002514	.0002711	.0002915	.0003127	.0003347	.0003574
4	.0003808	.0004050	.0004299	.0004554	.0004819	.0005091	.0005370	.0005656
5	.0005950	.0006251	.0006560	.0006876	.0007199	.0007530	.0007869	.0008215
6	.0008568	.0008929	.0009297	.0009672	.0010055	.0010445	.0010844	.0011249
7	.0011662	.0012082	.0012510	.0012944	.0013387	.0013837	.0014295	.0014759
8	.0015232	.0015711	.0016198	.0016693	.0017195	.0017705	.0018222	.0018746
9	.0019278	.0019817	.0020363	.0020916	.0021479	.0022048	.0022625	.0023209
10	.0023800	.0024398	.0025004	.0025618	.0026239	.0026867	.0027503	.0028147
11	.0028798	.0029456	.0030121	.0030794	.0031475	.0032163	.0032859	.0033561
12	.0034272	.0034990	.0035714	.0036447	.0037187	.0037934	.0038690	.0039452
13	.0040222	.0040999	.0041783	.0042576	.0043375	.0044182	.0044997	.0045819
14	.0046648	.0047484	.0048328	.0049181	.0050039	.0050906	.0051780	.0052661
15	.0053550	.0054446	.0055349	.0056261	.0057179	.0058105	.0059039	.0059979
16	.0060928	.0061884	.0062847	.0063817	.0064795	.0065780	.0066774	.0067774
17	.0068782	.0069797	.0070819	.0071850	.0072887	.0073932	.0074985	.0076044
18	.0077113	.0078187	.0079268	.0080360	.0081452	.0082560	.0083672	.0084791
19	.0085918	.0087052	.0088193	.0089343	.0090499	.0091663	.0092835	.0094013
20	.0095200	.0096393	.0097594	.0098803	.0100019	.0101243	.0102474	.0103712
21	.0104958	.0106211	.0107472	.0108739	.0110015	.0111299	.0112589	.0113886
22	.0115192	.0116505	.0117825	.0119152	.0120487	.0121830	.0123179	.0124537
23	.0125902	.0127274	.0128654	.0130040	.0131435	.0132837	.0134247	.0135664
24	.0137088	.0138519	.0139959	.0141405	.0142859	.0144321	.0145789	.0147266
25	.0148750	.0150241	.0151739	.0153246	.0154759	.0156280	.0157809	.0159345
26	.0160888	.0162439	.0163997	.0165563	.0167135	.0168716	.0170304	.0171899
27	.0173502	.0175112	.0176729	.0178355	.0179988	.0181627	.0183275	.0184929
28	.0186592	.0188262	.0189939	.0191624	.0193316	.0195015	.0196722	.0198436
29	.0200158	.0201887	.0203624	.0205368	.0207119	.0208879	.0210645	.0212418
30	.0214200	.0215988	.0217785	.0219588	.0221399	.0223218	.0225044	.0226877
31	.0228718	.0230566	.0232422	.0234285	.0236155	.0238033	.0239919	.0241812
32	.0243712	.0245619	.0247535	.0249457	.0251387	.0253325	.0255269	.0257222
33	.0259182	.0261149	.0263124	.0265106	.0267096	.0269092	.0271097	.0273109
34	.0275128	.0277155	.0279189	.0281231	.0283279	.0285336	.0287399	.0289471
35	.0291550	.0293636	.0295729	.0297831	.0299939	.0302056	.0304179	.0306309
36	.0308448	.0310594	.0312747	.0314908	.0317075	.0319251	.0321434	.0323624
37	.0325822	.0328027	.0330239	.0332460	.0334687	.0336923	.0339165	.0341415
38	.0343672	.0345937	.0348209	.0350489	.0352775	.0355070	.0357372	.0359681
39	.0361998	.0364322	.0366654	.0368993	.0371339	.0373694	.0376055	.0378424
40	.0380800	.0383184	.0385575	.0387973	.0390379	.0392793	.0395214	.0397642
41	.0400078	.0402521	.0404972	.0407430	.0409895	.0412368	.0414849	.0417337
42	.0419833	.0422335	.0424845	.0427362	.0429887	.0432420	.0434959	.0437507
43	.0440062	.0442624	.0445194	.0447771	.0450355	.0452947	.0455547	.0458154
44	.0460768	.0463389	.0466019	.0468655	.0471299	.0473951	.0476609	.0479276
45	.0481950	.0484631	.0487320	.0490016	.0492719	.0495430	.0498149	.0500875
46	.0503608	.0506349	.0509097	.0511853	.0514615	.0517386	.0520164	.0522949
47	.0525742	.0528542	.0531349	.0534165	.0536988	.0539818	.0542655	.0545499
48	.0548352	.0551212	.0554079	.0556953	.0559835	.0562725	.0565622	.0568526
49	.0571438	.0574357	.0577284	.0580218	.0583159	.0586109	.0589065	.0592029
50	.0595000	.0597979	.0600965	.0603959	.0606959	.0609969	.0612984	.0616007
51	.0619038	.0622076	.0625122	.0628175	.0631235	.0634304	.0637379	.0640462
52	.0643552	.0646649	.0649753	.0652867	.0655987	.0659115	.0662250	.0665392
53	.0668542	.0671699	.0674864	.0678036	.0681215	.0684402	.0687597	.0690799
54	.0694008	.0697225	.0700449	.0703681	.0706920	.0710166	.0713419	.0716681
55	.0719950	.0723226	.0726510	.0729801	.0733099	.0736406	.0739719	.0743039
56	.0746368	.0749704	.0753047	.0756398	.0759755	.0763120	.0766494	.0769874
57	.0773262	.0776657	.0780060	.0783476	.0786887	.0790312	.0793745	.0797185
58	.0800632	.0804087	.0807549	.0811019	.0814495	.0817980	.0821472	.0824971
59	.0828478	.0831992	.0835514	.0839043	.0842579	.0846123	.0849675	.0853234
60	.0856800	.0860374	.0863955	.0867543	.0871139	.0874743	.0878354	.0881973

To Use the Table. If the diameter of the piston is an even number, the constant is found in the second column; if it contains a fraction the constant is found by following the column horizontally until the required fraction is reached. The constant multiplied by the piston speed in feet per minute and by the M. E. P. in pounds per square inch gives the I. H. P.

Example. An engine runs at 75 revolutions. The stroke is 4 feet; if the M. E. P. is 48 pounds and the piston 27⅜ inches in diameter what is the I. H. P.

From the table the constant for a piston 27⅜ inches in diameter is .0178355. The piston speed is $150 \times 4 = 600$ feet per minute. Then the I. H. P. is,

$$.0178355 \times 600 \times 48 = 513.66$$

The horse-power as above calculated is called the indicated horse-power and is usually written I. H. P. Although the above calculation shows the amount of power the engine develops it does

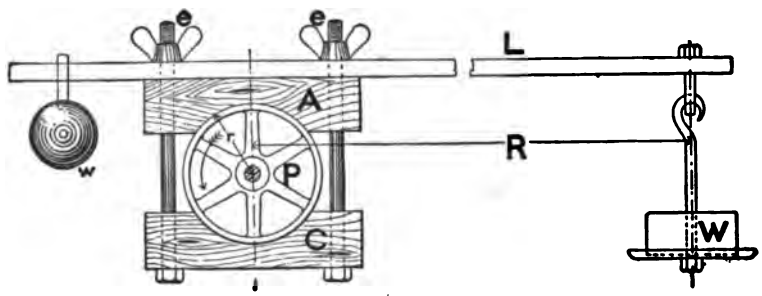


Fig. 18.

not show the *available* power since part of the indicated horse-power is used to run the engine itself, that is, to overcome the friction of the parts. To determine how much power can be used to run machinery some form of absorption dynamometer or friction brake is attached to the engine. The power thus obtained is called the **Brake Horse Power** or B. H. P. It is more satisfactory for both the owner and builder to know the B. H. P. than to know the I. H. P.

The Prony Brake, Fig. 18, is one of the simplest absorption dynamometers. The two wooden blocks A and C are held together against the rim of the pulley P by bolts. The thumb-nuts, *e*, *e*, being

used to adjust the pressure. By means of the bolts the arm L is held to the upper block. From this arm is suspended the ball weight, w, which by sliding along the arm counterbalances the weight of the arm and pan at the other end. The pulley revolves at the required speed in the direction indicated by the arrow. The bolts are tightened until the lever remains stationary in a horizontal position when a known weight, W, is hung at the end.

The amount of work absorbed by the brake depends upon the weight W, the length, R, and the speed. It is independent of the diameter of the pulley and the pressure of the block because the moments of force about the center of the pulley are equal when the lever L, is horizontal. Letting f equal the co-efficient of friction, p the pressure of the blocks and r the radius of the pulley,

$$f\,p\,r = \mathrm{W\ R}$$

The work done at the face of the pulley equals the force multiplied by the distance or the pressure multiplied by the number of feet passed through.

Let N = the number of revolutions per minute. Then the distance passed through per minute equals $2\,\pi\,r\,\mathrm{N}$ and the work done equals $2\,\pi\,r\,\mathrm{N}\,f\,p$. Then as $f\,p\,r = \mathrm{W\ R}$, the work done at the rim of the pulley equals the left hand side of the equation multiplied by $2\,\pi\,\mathrm{N}$, and to keep both sides equal we multiply W R by $2\,\pi\,\mathrm{N}$. Hence the work done is expressed by the formula

$$2\,\pi\,\mathrm{N\ W\ R}$$ and,

$$\mathrm{B.\ H.\ P.} = \frac{2\,\pi\,\mathrm{N\ W\ R}}{33{,}000}$$

$$= .0001904\ \mathrm{N\ W\ R}$$

A Prony brake with an arm 4 feet long was attached to the pulley on the fly wheel of an engine. The weight in the scale pan was 50 pounds and the speed of the engine 300 revolutions. Find the brake horse power.

$$\mathrm{B.\ H.\ P.} = .0001904 \times 300 \times 50 \times 4$$

$$= 11.424$$

The **rope brake** shown in Fig. 19 is easily constructed of material at hand and being self-adjusting needs no accurate fitting. For large powers the number of ropes may be increased. It is considered a most convenient and reliable brake. In Fig. 19 the spring

balance, B, is shown in a horizontal position. This is not at all necessary; if convenient the vertical position may be used. The ropes are held to the pulley or fly-wheel face by blocks of wood, O. The weights at W may be replaced by a spring balance if desirable.

To calculate the Brake Horse Power, subtract the pull registered by the spring balance, B, from the load at W. The lever arm is the radius of the pulley plus $\frac{1}{2}$ the diameter of the rope. The formula is,

$$\text{B. H. P.} = \frac{2\,\pi\,\text{R}\,\text{N}\,(\text{W}-\text{B})}{33{,}000}$$

$$= .0001904\ \text{R}\ \text{N}\ (\text{W}-\text{B})\ *$$

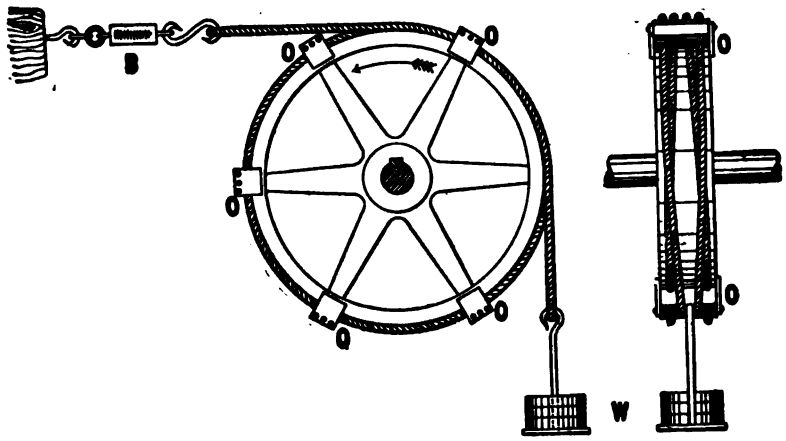


Fig. 19.

Example. A rope brake is attached to a gas engine. The average reading of the spring balance is 8 pounds. W = 80 pounds. If the radius of the brake wheel is 28 inches and the rope 1 inch in diameter, what is the B. H. P. when the engine makes 350 revolutions per minute?

$$\text{R} = 28 + \tfrac{1}{2} = 28\tfrac{1}{2} \text{ inches} = \tfrac{28.5}{12} \text{ feet}$$

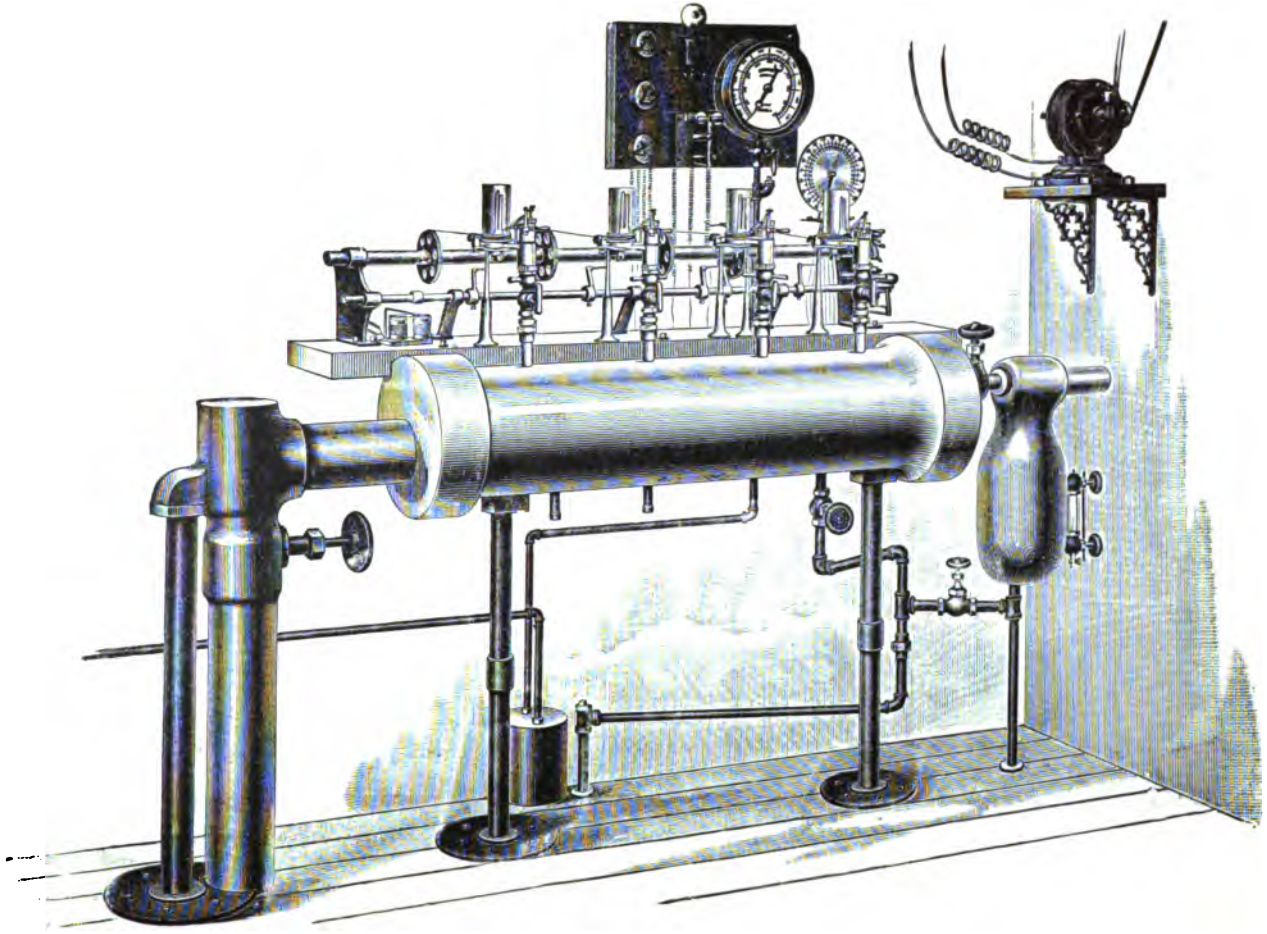
$$\text{B. H. P} = .0001904\ \text{R}\ \text{N}\ (\text{W}-\text{B})$$

$$= .0001904 \times \tfrac{28.5}{12} \times 72 \times 350$$

$$= 11.4 \text{ Ans.}$$

If both the indicated horse-power and the brake horse-power

* Note: If B is greater than W, the engine is running in the opposite direction. Use the formula B. H. P. = .0001904 R N (B − W).



MERCURY COLUMN FOR CALIBRATING INDICATOR SPRINGS.

American Steam Gauge and Valve Manufacturing Company.

are known the power used in friction is found by subtracting the B. H. P. from the I. H. P.

The **mechanical efficiency** of the engine is the **ratio** of the B. H. P. to the I. H. P. or,

$$E = \frac{\text{B. H. P.}}{\text{I. H. P.}}$$

If an engine of 18.2 indicated horse-power develops at a trial 16.02 brake horse-power, what is its mechanical efficiency?

$$E = \frac{\text{B. H. P.}}{\text{I. H. P.}}$$

$$= \frac{16.02}{18.2} = .88$$

$$= 88\ \% \text{ Efficiency.}$$

Brakes should be well lubricated. For small powers the heat generated by friction between the ropes or blocks and the rim of the wheel, will be conducted away by radiation but for large powers some additional means is necessary. In case there are flanges on the wheel, water can be introduced into the wheel, the flanges keeping it from flowing out and centrifugal force keeping it in contact with the rim. The amount of water can be regulated so that all may be evaporated, or a scoop can be arranged to carry off the water. In all cases the water should flow continuously.

To Find the Area of Cards. M. E. P. or the mean effective pressure is equal to the area of the indicator diagram divided by the length. The length is easily found by measurement but to find the area is more difficult since the shape is irregular. If the figure were regular its area could be found by geometry or by simple formulas.

The area of the indicator card can be found in two ways. By dividing the diagram into sections and by the use of a planimeter. The former is only an approximate method; the area thus found is nearly correct if the number of divisions is great.

Tangents at each end, perpendicular to the atmospheric line are first drawn. The horizontal distance between these tangents is then divided into 10 or more equal parts. The horizontal length of each section is then divided into two equal parts and lines perpendicular to the atmospheric line drawn through these points of

division. The sum of the lengths of all these lines is divided by the number of lines to get the average. This average length or average ordinate multiplied by the scale of spring gives the mean effective pressure.

Fig. 20 is the card from the crank end of an engine. The

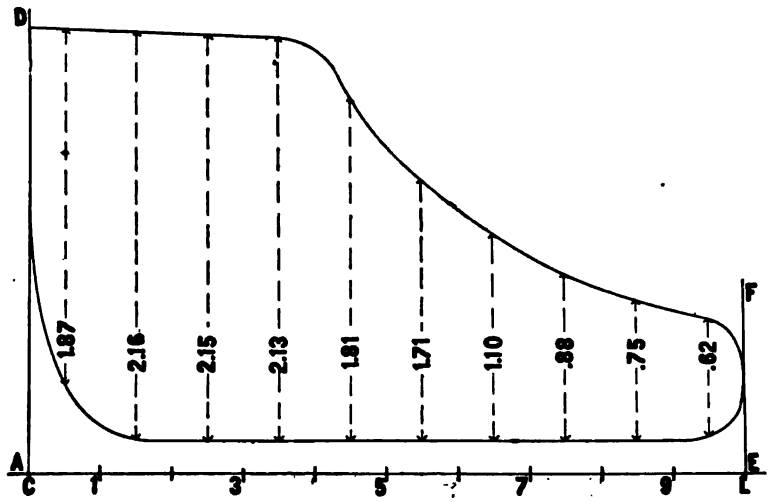


Fig. 20.

line C L is the atmospheric line and the lines A D and E F are drawn perpendicular to it and tangent to the extreme ends of the diagram. The line A E is divided into 10 equal parts and lines

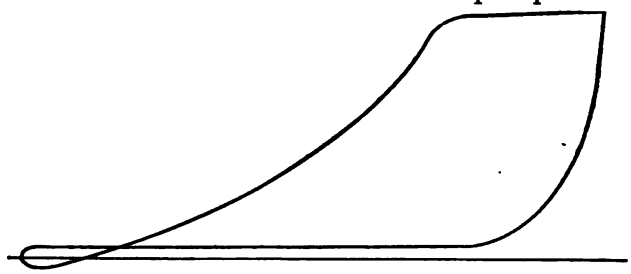


Fig. 21.

are drawn through points marking the centers of the divisions. On each of these lines the length is marked. The sum of the lengths is 15.18 and 15.18 divided by 10 is 1.518. If the scale of spring is 40 pounds, 1.518 multiplied by 40 is the M. E. P. or 60.7 = M. E. P.

The horizontal length may be divided into any number of equal parts but 10 or 20 makes the computation easy. The operation of finding the M. E. P. for the head end is exactly the same. The average M. E. P. for one revolution of the engine is the average of the two mean effective pressures.

In case the diagram is very irregular it should be divided into 20 equal parts instead of 10. If there is a loop in the diagram as shown in Fig. 21 the area of the loop must be subtracted

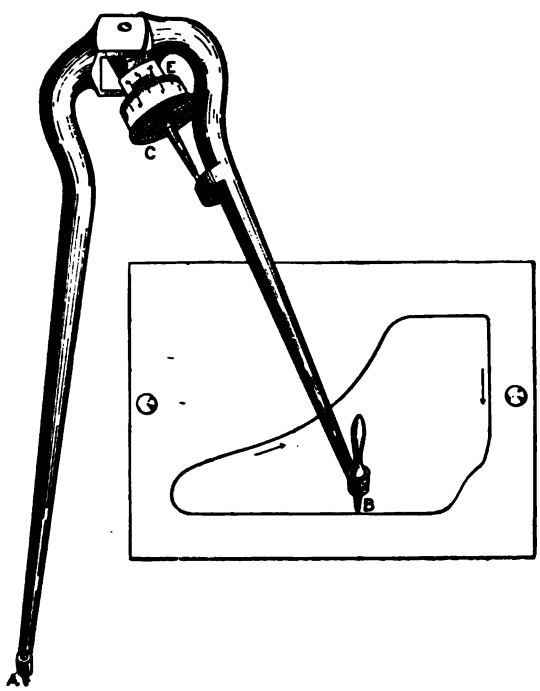


Fig. 22.

from the area of the other part as it represents work done by the piston on the steam and therefore loss.

The lengths may be marked off on a piece of paper if a good scale is not at hand.

A more accurate result is obtained by using an instrument called the **planimeter.** There are several planimeters and averaging instruments in common use for determining the mean effective pressure of indicator cards. The planimeter shown in Fig.

22 is one of the most simple and is called the Amsler Polar Planimeter from its inventor Prof. Amsler. The cut is about one-half the size of the instrument. It consists of two arms free to move about a pivot and a roller graduated in inches and tenths of inches. A vernier is placed with the roller so the areas may be read in hundredths of a square inch. The point A is kept stationary and the tracer B is moved once around the outline of the diagram. The area in square inches of the diagram is read from the roller C and the vernier E.

To Use the Planimeter. The diagram should be fastened to some flat unglazed surface, such as a drawing board, by means of thumb tacks, springs or pins. The point A is pressed into the paper so that it will hold in place. The point B is set at any point in the outline of the diagram and the roller set at zero. Follow the outline of the diagram carefully in the direction of the hands of a watch as indicated by the arrows in Fig. 22 until the tracer has moved completely around the diagram. The result is then read to hundredths of an inch from the roller. Suppose after tracing over the outline we find that the largest figure that has passed the zero of the vernier is 8; the number of graduations (tenths) that have passed the zero to be 5 and the number (hundredths) of the graduations in the roller that exactly coincides with a graduation on the vernier to be 9. Then the area is 8.59 square inches.

Often at the start the roller is not adjusted so that the zeros coincide but the reading is taken and subtracted from the final reading. Thus if the first reading is 4.63 and the second 7.31 the area is $7.31 - 4.63 = 2.68$ square inches. In case the second reading is less than the first, add 10 to the second reading then subtract.

This instrument is very valuable to an engineer who takes indicator cards. The results obtained are very accurate, the error being small. Ten or twelve diagrams can be measured by this instrument in the same time that is necessary to measure a single card by the method of ordinates.

It is well to run over the area three or four times and take an average as the tracing of the diagram cannot be absolutely correct at any time.

THERMAL EFFICIENCY.

The **thermal efficiency** of the steam engine is found in the same manner as that of any other heat engine. The efficiency depends upon the limits of temperature and not upon the nature of the working medium.

Let T_1 = absolute temperature of the heat received by the engine.

T_2 = absolute temperature of the heat rejected by the engine.

E = efficiency of engine.

Then,

$$E = \frac{T_1 - T_2}{T_1}$$

or, the efficiency equals the temperature of the heat rejected, subtracted from the temperature of the heat received and the result divided by the temperature of the heat received.

Suppose an engine is supplied with steam at 120 pounds absolute pressure and the exhaust is atmospheric pressure. What is the efficiency?

The absolute temperature corresponding to 120 pounds absolute pressure is 341.05° + 461° and the temperature of atmospheric pressure is 212° + 461°.

Then,

$$E = \frac{802.05 - 673}{802.05} = .16 \text{ or } 16 \text{ per cent.}$$

If the engine had been of the condensing type and the exhaust pressure one pound above the vacuum, the efficiency would be as follows:

The temperature of one pound absolute pressure is 101.99° + 461°.

$$E = \frac{802.05 - 562.99}{802.05} = .30 \text{ or } 30 \text{ per cent.}$$

In actual engines this efficiency cannot be obtained because the difference between the amount of heat received and that rejected is not all converted into work. Part of it is lost by radiation, conduction, leakage, etc. Also cylinder condensation reduces the efficiency.

The Theoretical Indicator Diagram. An indicator diagram is the result of two movements; a horizontal movement of the

paper and a vertical movement of the pencil. The horizontal movement exactly corresponds to the movement of the piston of the engine and the vertical movement exactly corresponds to the pressure of steam in the cylinder.

The shape of the indicator card depends upon the manner in which steam is admitted to and released from the cylinder. Different engines give different shaped indicator cards and the cards taken from an engine vary with the conditions. Figs. 1 and 2 show theoretical indicator cards from a non-condensing engine without clearance; the former being for the case that has admission during the whole stroke. The diagram of Fig. 2 shows the cut off at $\frac{1}{2}$ stroke. All practical engines have clearance and slight compression; so the theoretical diagram assumes the shape shown in Fig. 23. In this card the admission line H A is vertical, the steam line A C is horizontal, the expansion line C D an hyperbolic curve, the exhaust line D B vertical, the back pressure line B F horizontal and the compression curve an hyperbola. The **actual** shape is somewhat different from the **theoretical** mainly because the valves do not open and close quickly, the ports offer some resistance to the passage of the steam and the back pressure is neither atmospheric in the non-condensing engine nor absolute vacuum in the condensing engine.

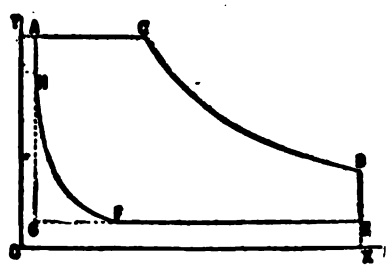


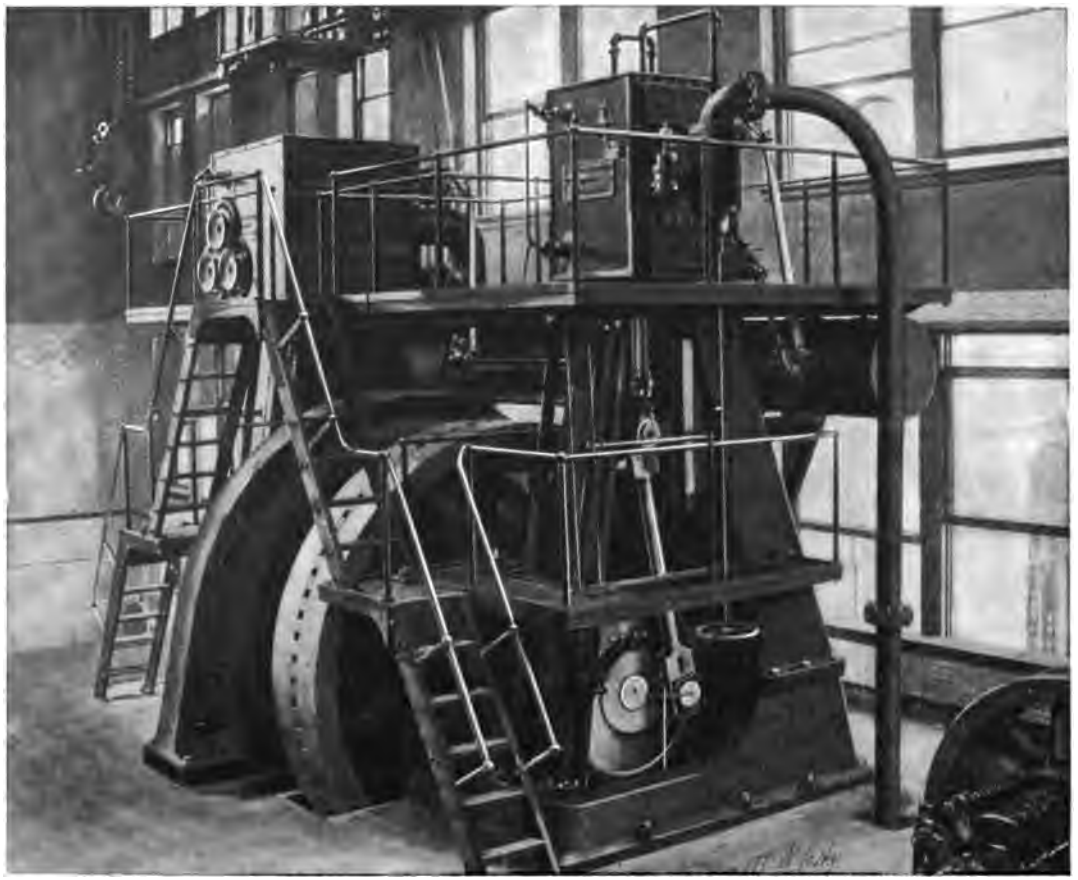
Fig. 23.

The diagram shown in Fig. 24 is a practical diagram and like those taken from engines.

The **atmospheric line** L M is the line drawn by the pencil of the indicator when the connection to the engine is closed and both sides of the piston of the indicator are open to the atmosphere. It is the zero of the steam gage.

The **admission line** H A shows the rise of pressure due to the admission of steam to the cylinder. If the steam is admitted quickly when the engine is nearly on dead center this line will be very nearly vertical.

The **steam line** A C is drawn while the valve admits steam



700 Horse-power Vertical Cross-compound McIntosh-Seymour Engine, with Direct-driven Multiphase Generator.

to the cylinder. This line is horizontal if there is no wire-drawing.

The **point of cut off** C, indicates the point at which the admission of steam is stopped by the closing of the valve. This point is rounding since the valve closes slowly. Sometimes it is difficult to determine the exact point where cut off takes place; it is usually where the curve changes from concave to convex.

The **expansion curve** C D shows the fall in pressure as the steam expands while the piston moves toward the end of the stroke.

The **point of release** D shows the point at which the exhaust

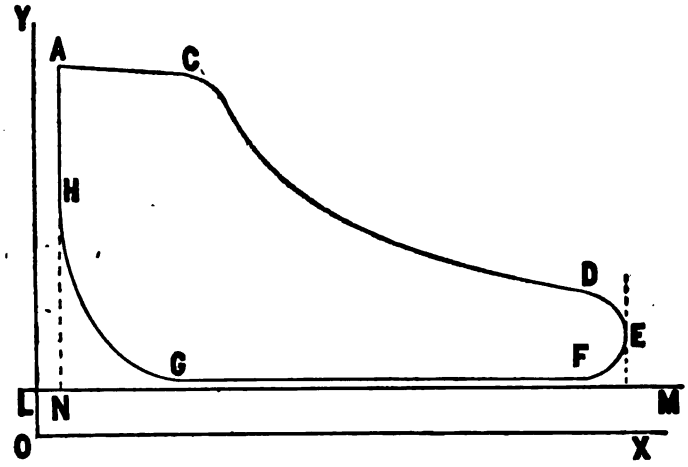


Fig. 24.

valve opens. The rounding is due to the slow action of the valve when opening. Because of this slow action of the valve, release begins a little before the end of the forward stroke.

The **exhaust line** D E F represents the loss in pressure which occurs while the valve opens to exhaust at and near the end of the stroke.

The **back pressure line** F G shows the back pressure against which the piston acts during the return stroke. For a condensing engine this line is below the atmospheric line L M, the distance below being dependent upon the state of the vacuum in the condenser. For cards taken from a non-condensing engine the back pressure line is a little above the atmospheric line.

The **point of exhaust closure** G is the point where the valve

closes to exhaust. The exact point is not clearly defined as the curve shows a change of pressure due to the gradual closing of the valve.

The **compression curve** G H shows the rise of pressure due to the compression of the steam remaining in the cylinder after the valve has closed to exhaust.

The **zero line** of pressure or line of absolute vacuum O X is drawn below and parallel to the atmospheric line. The distance between the lines O X and L M represents 14.7 pounds pressure.

The **clearance line** O Y is drawn perpendicular to the line of absolute vacuum and at a distance from the end of the diagram

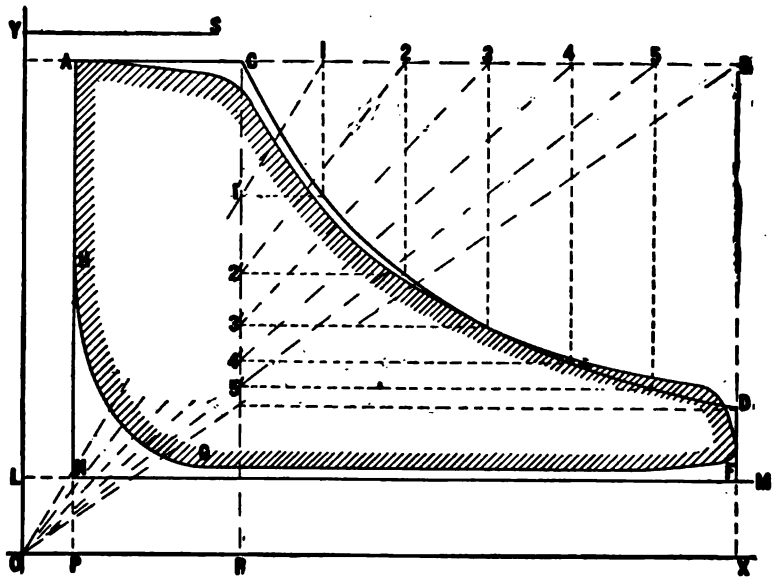


Fig. 25.

equal to the same per cent. of the length of the diagram as the clearance volume is of the piston displacement, or

$$\frac{\text{L N}}{\text{L M}} = \frac{\text{clearance volume}}{\text{volume of cylinder}}.$$

It is readily seen that the area of an actual indicator diagram is less than that of a theoretical card. This is because of the round corners at cut off and exhaust, the back pressure and the compression. Sometimes it is useful, especially in designing engines, to draw the theoretical indicator card.

To Draw the Theoretical Card. To draw an ideal diagram draw P X equal to the length of stroke and O P equal to the clearance shown in Fig. 25. Draw O Y and P A perpendicular to O X and draw Y S parallel to O X and at a height corresponding to the boiler pressure.

The line of initial pressure A C is then drawn parallel to Y S and is usually taken as from 90 to 95 per cent. of the boiler pressure if there is no special cause for loss. Then take A C as the portion of the stroke at which steam is admitted so that $\frac{P X}{A C} =$ the ratio of expansion. The expansion line is considered a hyperbolic curve with O Y and O X as asymptotes. To draw the hyperbolic curve. First draw the line A C B parallel to the atmospheric line and F D B and R C perpendicular to it. Then make points 1, 2, 3, 4, etc., on C B and connect them with the point O. At the points 1′, 2′, 3′, 4′, etc., where these lines intersect the line R C draw parallels to C B until they meet perpendiculars from 1, 2, 3, 4. The point of intersection of these lines are points in the hyperbolic curve C D, as shown in Fig. 25. Any number of points may be used; but there must be enough to determine the curve.

The area A C D F N H is the theoretical card, with a given boiler pressure, ratio of expansion and an assumed back pressure. The actual card for the same data would be more nearly like the shaded area which lies mostly within the outline of the theoretical card. In designing engines it is well to know the ratio of the actual to the ideal card for all types of engines.

This ratio varies with the speed, type of engine, and kind of valves and has the following values.

For ordinary plain slide valve engines,	.8 to .9
For small engines, about,	.85
For large engines, about,	.90
For engines with high speed, about,	.75
For compound engines,	.75 to .80
For compound engines, high speed,	.65 to .75
For triple expansion engines,	.60 to .70
For triple expansion engines, high speed,	.50 to .60

CARDS FOR COMPOUND ENGINES.

In Fig. 26 the ideal cards of a **tandem** compound engine of the Woolf type are shown. The diagram A C D E F G H is from the high pressure cylinder and the diagram L M N P Q R from the low pressure. S T is the atmospheric line.

The line H A is the admission line, A C the steam line, and C D the expansion line. These lines are similar to those of a single cylinder engine diagram. At D, the point of release, the pressure drops slightly as steam is admitted to the low pressure

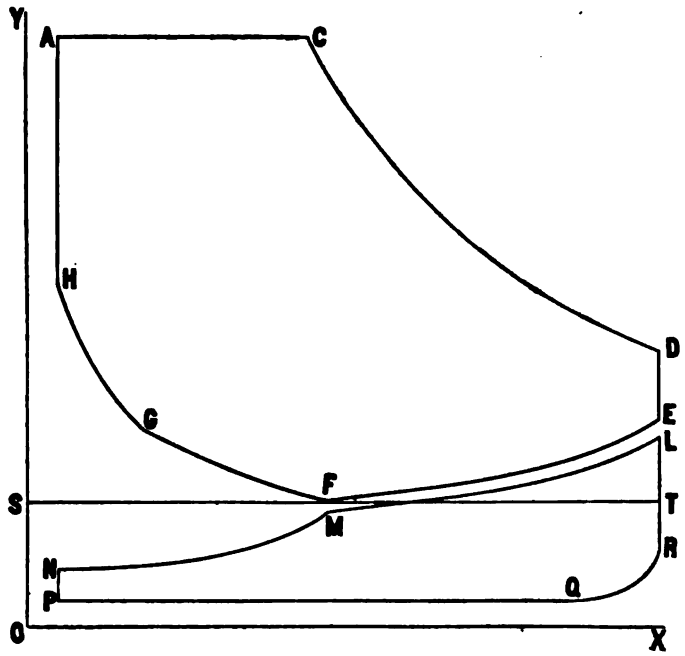


Fig. 26.

cylinder. The back pressure line E F, of the high pressure cylinder is parallel to the steam line L M, of the low pressure cylinder. They would coincide if there were no resistance to the flow of steam and no heat loss. The flow of steam from the high to the low pressure cylinder is cut off at F and the steam remaining in the high pressure cylinder is compressed in the cylinder and in the pipes. The exhaust closes at G and steam is compressed in the small cylinder from G to H.

Cut off occurs in the low pressure cylinder at M, and the steam in the cylinder expands, the curve M N being an equilateral hyperbola. Release takes place at N and the pressure falls to that of the condenser. The back pressure line P Q and the compression curve Q R are like those of a single engine.

The diagrams shown in Fig. 27 are from a Woolf engine. The lines are similar to those of the theoretical diagram shown in Fig. 26.

With compound engines of the Woolf type the steam passes

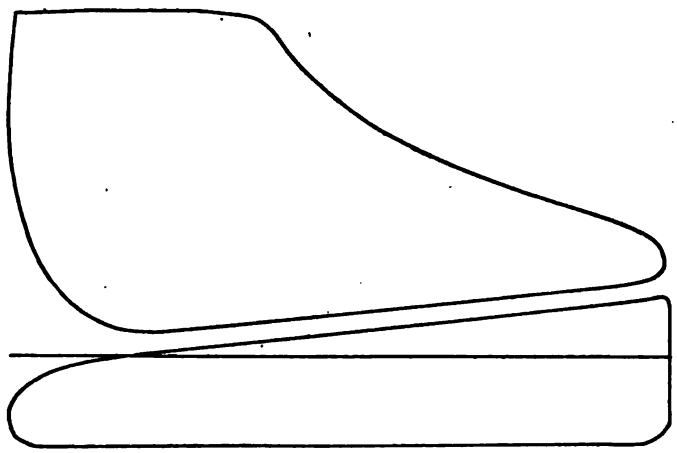


Fig. 27.

directly from the high pressure cylinder to the low pressure. In the **cross** compound, the cranks being at 90°, the piston in one cylinder is at the *end* of the stroke when the other is at the *middle* of the stroke. Therefore, a **receiver** must be used. The ideal cards from a cross compound engine are shown in Fig. 28. The dimensions are as follows:

Volume of high pressure cylinder	=	5 cu. ft.
Volume of receiver	=	5 cu. ft.
Volume of low pressure cylinder	=	15 cu. ft.
Cut off of high pressure cylinder	=	$\frac{1}{4}$ stroke.
Cut off of low pressure cylinder	=	$\frac{1}{2}$ stroke.
Initial pressure (absolute)	=	120 lbs.
Back pressure (absolute)	=	3 lbs.

Clearance and compression are not considered. The stroke of the high pressure cylinder begins at A. Steam is cut off at $\frac{1}{4}$ stroke at C.

Since steam is cut off at $\frac{1}{4}$ stroke, the ratio of expansion in the high pressure cylinder is 4. Then the volume of steam at D is 4 times that at C and since $p\ v = p_1\ v_1$, the pressure at D is $\frac{120 \times 1}{4} = 30$ pounds. Steam is released at D and passes to the receiver. The pressure at release, L, of the low pressure cylinder is found from the equation $p\ v = p_1\ v_1$. The volume of steam in the high pressure cylinder at cut off, is $\frac{5}{4}$ cubic feet and the

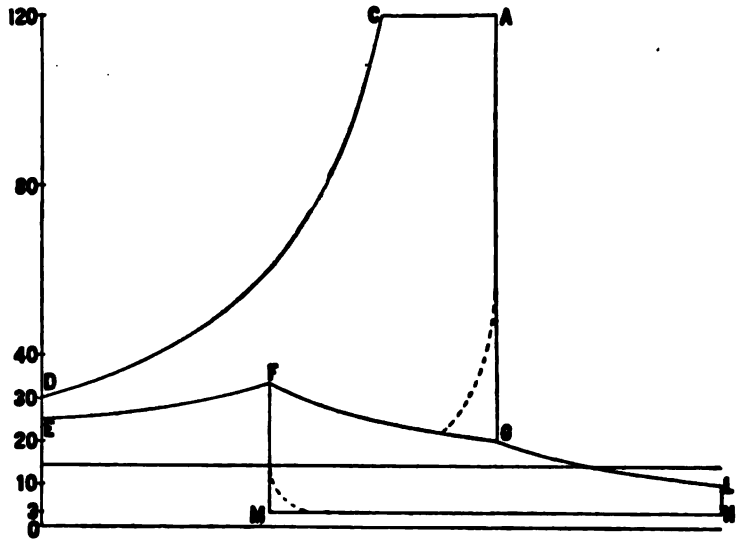


Fig. 28.

volume at L is 15 cubic feet; then the total ratio of expansion is $15 \div \frac{5}{4} = 12$. Then the pressure at L is $\frac{120 \times 1}{12} = 10$ pounds.

Since the low pressure cylinder cuts off at $\frac{1}{2}$ the stroke the volume at G is $\frac{1}{2}$ that at L.

Then as $p\ v = p_1\ v_1$, $p \times \frac{1}{2} = 10 \times 1$, or $p = 20$ pounds.

Hence the pressure at G is 20 pounds.

We can now find the pressure at E. The pressure in the receiver when the low pressure cylinder cut off, was 20 pounds because the low pressure cylinder was in communication with it.

Then as the piston in the small cylinder is at the end of the stroke when the steam is cut off in the large cylinder, steam at 30 pounds pressure rushes from the high pressure cylinder into the receiver and mixes with steam at 20 pounds pressure. When steam is cut off in the low pressure cylinder the high pressure cylinder and the receiver are in communication with each other; the total volume being the volume of the high pressure cylinder plus that of the receiver or $5 + 5 = 10$ cubic feet. What we wish to find is the pressure of the steam of this volume. The formula is,

$$P\ V = p\ v + p_1\ v_1.$$

Since there are 10 cubic feet in the receiver and high pressure cylinder, the value of V is 10. The volume of steam in the high pressure cylinder is 5 cubic feet and its pressure is 30 pounds. The volume of steam in the receiver is 5 cubic feet and its pressure is 20 pounds, then,

$$10\ P = 5 \times 30 + 5 \times 20$$

$$P = \frac{250}{10} = 25 \text{ pounds.}$$

Then the pressure at E = 25 pounds.

While the piston of the high pressure cylinder is on the return stroke, steam in that cylinder is compressed from E to F; the volume being 10 cubic feet. When the piston has completed $\frac{1}{2}$ the return stroke, the volume at F is equal to $\frac{1}{2}$ the volume of the high pressure plus the volume of the receiver or $\frac{5}{2} + 5 = 7\frac{1}{2}$ cubic feet.

Then with the formula $p\ v = p_1\ v_1$ we obtain,

$$p = \frac{25 \times 10}{7\frac{1}{2}} = 33.33$$

or the pressure at F is 33.33 pounds.

Then as the cranks are 90° apart, and the high pressure piston is at the middle of the stroke, the low pressure piston must be at the beginning of its stroke; or the pressure in the low cylinder is the same as that in the high and in the receiver, or 33.33 pounds. Since the stroke is beginning in the low pressure cylinder, steam is being admitted to it from the receiver and consequently the pressure in the large cylinder falls as the volume increases, which

is shown by the line F G. Cut-off occurs in the low pressure cylinder at G, and the steam expands until the piston reaches L; the curve being an equilateral hyperbola. At L the release occurs and the pressure drops to that in the condenser; in this case about 3 pounds. The back pressure line is of course the pressure in the condenser.

The cards of Fig. 29 are from a cross compound engine. The rise of pressure in the middle of the back pressure line of the

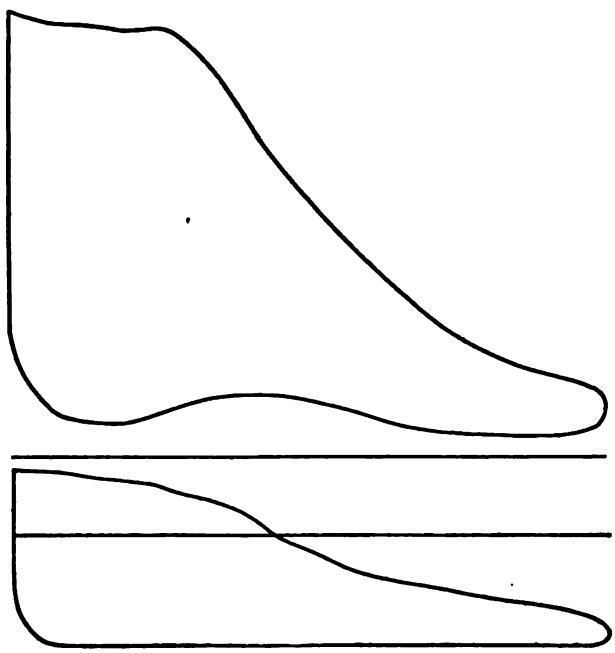


Fig. 29

diagram from the small cylinder is due to the fluctuation of pressure in the receiver.

COMBINED DIAGRAMS.

The indicator cards of multi-cylinder engines may be combined so that the pressures and volumes are shown in their proper relations. To do this, the cards are reduced to the same scale of pressure and the same scale of volume. To make the combined diagram of convenient size, the length of the low-pressure card is

left as it is and the length of the high-pressure diagram is shortened in the ratio of the cylinder volumes.

Perhaps the best way to show the method is by an illustration. The cards shown in Fig. 30 were taken from a compound condensing engine.

Ratio of cylinder volumes = 1 : 3
Initial pressure = 138 pounds
Spring, high-pressure card = 60 pounds
Spring, low-pressure card = 30 pounds

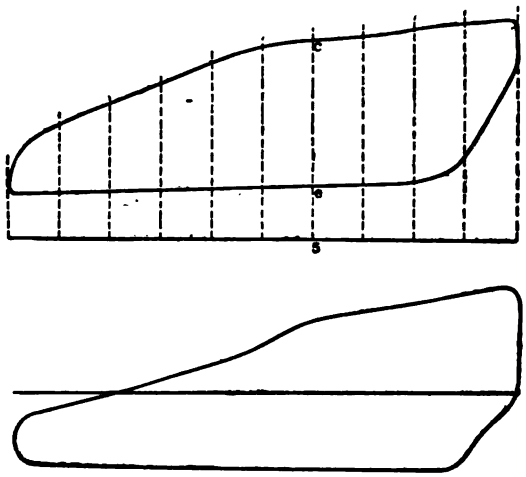


Fig. 30.

First draw the line of zero pressure A B and the line of zero volume E F (see Fig. 31). The line O P is drawn parallel to E F and at a distance proportional to the clearance of the low-pressure cylinder. Similarly the distance between M N and E F represents the clearance of the high-pressure cylinder. Now draw the atmospheric line C D. In this case it will be .49 inch above A B because a 30-pound spring is used, and $\frac{14.7}{30} = .49$. Reproduce the low-pressure card without change, as shown.

Divide the high-pressure card with 10 (or more) ordinates, and reproduce it with volumes and pressures of the same scale as the low-pressure card. Since a 60-pound spring was used, each ordinate will be twice as long (because $\frac{60}{30} = 2$). The distance

between the ordinates will be $\frac{1}{3}$ as great because the high-pressure cylinder is $\frac{1}{3}$ the volume of the low. Draw the ordinates as shown. The distance between ordinates L and M will be $\frac{1}{3}$ of the length of the high-pressure card. The points *c* and *e* are on the fifth ordinate, and are twice as far above the atmospheric line as they are in the original high-pressure card.

After locating all the points draw the curve through them. Now draw the theoretical expansion curve R S through the point of cut-off of the high-pressure cylinder by the method explained

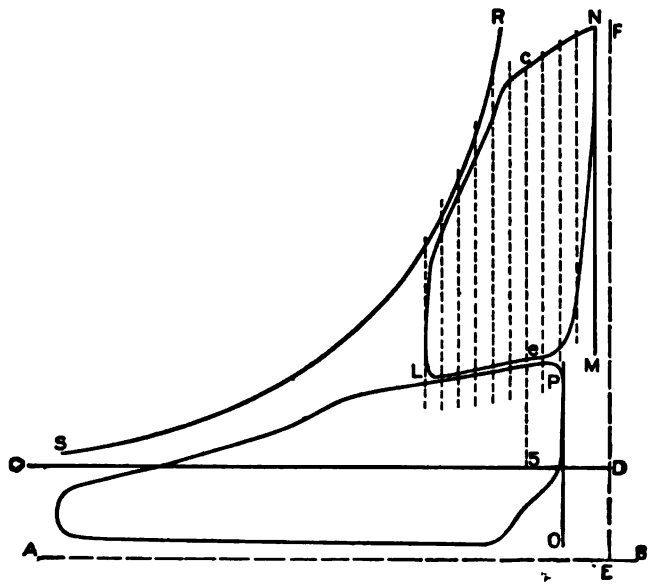


Fig. 31.

on page 89. The difference between the area included between the theoretical curve and the lines of no pressure and no volume, and the sum of the actual areas, represents approximately the losses.

This method is not strictly accurate, because all the steam used in the high-pressure cylinder does not pass to the low-pressure cylinder; a small portion is left for compression. By thus combining the cards the action of the valves may be discussed, provided such data as size, type and speed are known.

The combined diagram of a multi-expansion engine drawn

according to the above method is shown in Fig. 32. The volumes and pressures are first reduced to the scale of the low-pressure card. The cards are then redrawn at the proper distances from the lines of no pressure and no volume; the clearance in each cylinder being considered.

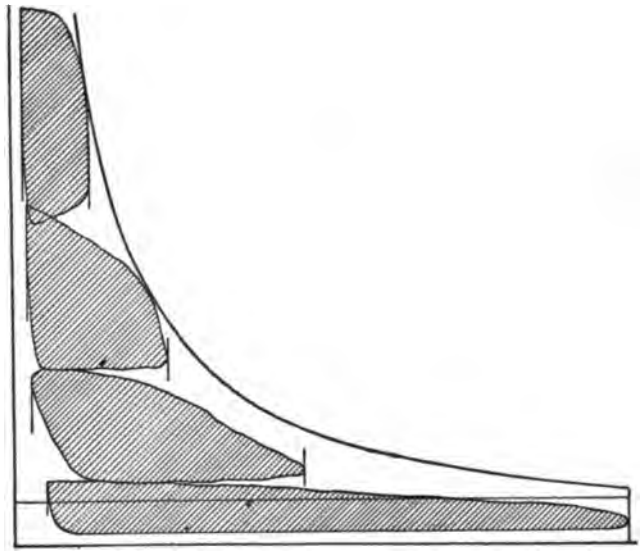


Fig. 32

HORSE-POWER OF COMPOUND ENGINES.

The I. H. P. of multi-cylinder engines may be found by adding the I. H. P. of the several cylinders. Another method is to reduce all the pressures to the area of the low-pressure cylinder. This is done by dividing the M. E. P. of each cylinder by the ratio of its volume to that of the low-pressure cylinder.

Suppose the M. E. P. of the high-pressure cylinder of a compound engine is 78 pounds as found from the indicator card. If the volume of the high-pressure cylinder is $\frac{1}{3}$ that of the low, the M. E. P. of the high referred to the low would be $\frac{78}{3} = 26$ pounds. Then if the card from the large cylinder shows a M. E. P. of 30 pounds, the total M. E. P. is $30 + 26 = 56$ pounds, and the I. H. P. is found by inserting 56 as the value of P and using the area of the low pressure as A, in the formula for I. H. P.

INDICATOR CARDS.

The indicator reveals defects in the steam distribution. That is, if the valve or valves are set so that the events of the stroke are *too early* or *too late* or if *more work* is done at one end of the cylinder than at the other, the engineer finds it out by examining the indicator card.

Sometimes an engine appears to run well and the owner is perfectly satisfied with it; but from the indicator diagrams it is found that considerable saving might be effected by correcting the defects in the valve setting.

On looking at a diagram one might say it was a faulty card

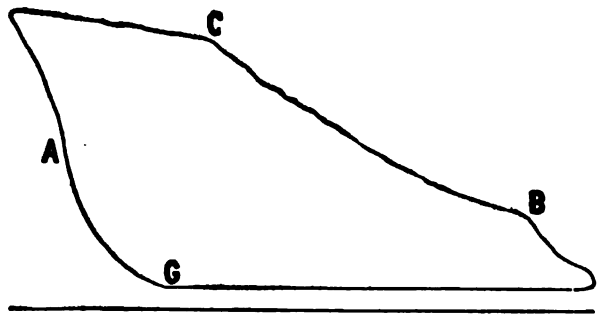


Fig. 33.

and yet for that type, size and speed it is perhaps the best that could be obtained from the engine. The same form of diagram is not possible from different types of engines. The diagram from a Corliss engine, having four valves, is different from that of the plain slide valve engine; also the diagrams from high speed engines differ from those of low speed.

The most common faults in the distribution of steam in the cylinder can be divided into four classes.

a = **Admission** too early or too late.
b = **Cut-off** too early or too late.
c = **Release** too early or too late.
d = **Compression** too early or too late.

In the following figures,

A is the point of admission,
C is the point of cut off,
B is the point of release,
G is the point of compression.

The diagram shown in Fig. 33 shows **too early admission.** The admission line curves *backward* instead of being straight and perpendicular to the atmospheric line as it is in Fig. 24. The diagram also shows cut off, release and compression early. When the valve is of the plain slide valve type *all* the events are likely to be too early if one of them is. The reason for the event being

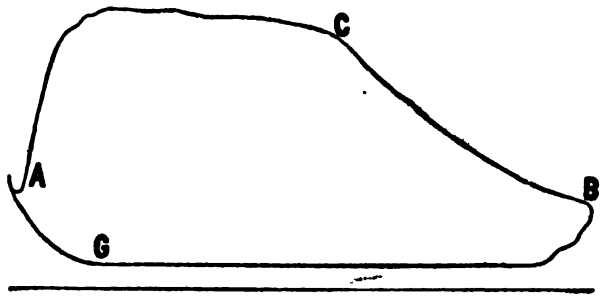


Fig. 34.

too early is that the eccentric has too much *angular advance.* Hence the remedy is to decrease the angular advance.

Fig. 34 shows a diagram having the opposite defects to those of Fig. 33. The events are too late. The admission line curves forward and the line shows that admission does not take place until after the stroke is well begun. Release occurs at the end of

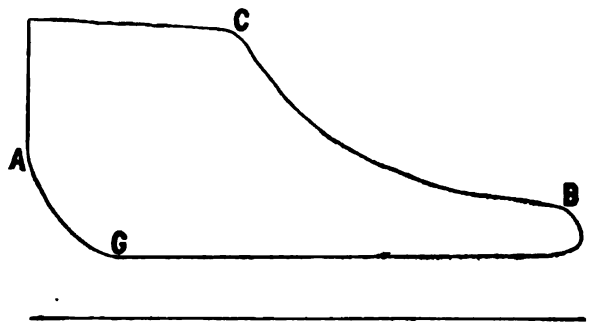


Fig. 35.

the stroke. In this case the angular advance of the eccentric should be increased until the admission line is perpendicular to the atmospheric line.

Fig. 35 shows a card having too much back pressure. This may be due to a small exhaust port or pipes, or the passage of steam

through coils of pipe for heating. The card shows the other events to be good. A diagram having **too late cut off** is shown in Fig. 36. The pressure at release is high. When the engine is running under this condition much of the benefit from expansion is lost.

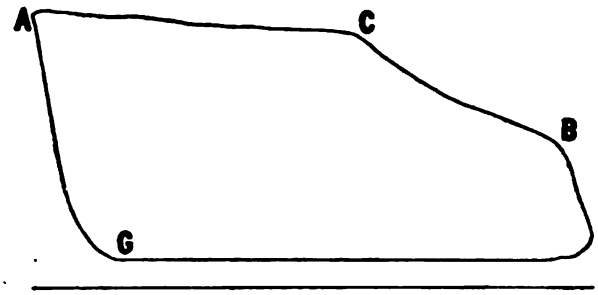


Fig. 36.

A diagram from a condensing engine is shown in Fig. 37. These oscillations are caused by the vibration of the indicator piston and spring. To avoid these vibrations never use a very light spring for high speed.

The diagram of Fig. 21 shows **too early cut off.** In this case the cut off is so early that the expansion line extends *below* the

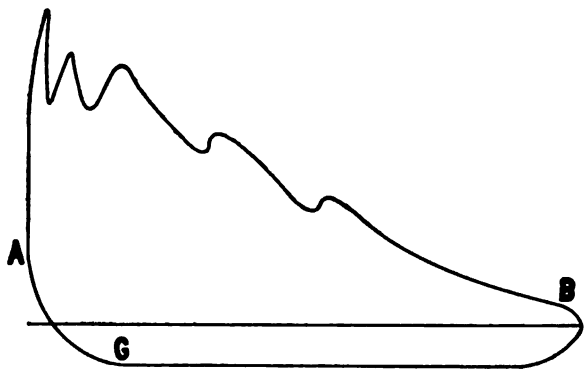


Fig. 37.

atmospheric line making a loop. The area of the loop must be *subtracted* from the area of the card as explained on page 33.

Fig. 38 shows a pair of diagrams from a plain slide valve engine. The admission lines are good. The sloping steam lines

show wire-drawing due to the slow action of the valve or too small ports or pipes. This wire-drawing decreases the area of the card which indicates loss. The greatest fault is the inequality of area of the diagram for the ends. The late cut off and consequent late compression of one end causes more area than the too early cut off and too early compression of the other end. These

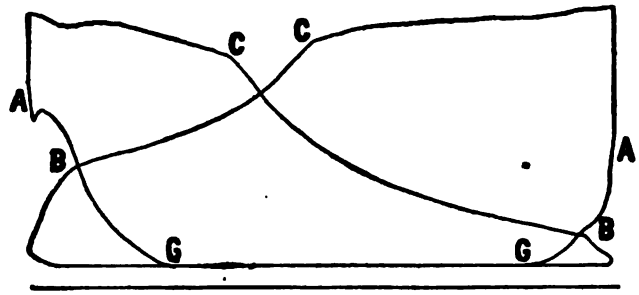


Fig. 38.

cards can be improved by adjusting the angular advance of the eccentric and the length of the valve rod.

The diagram of Fig. 39 indicates too early compression. The compression curve extends above the initial pressure line. The area of the loop must be subtracted from the card area, when com-

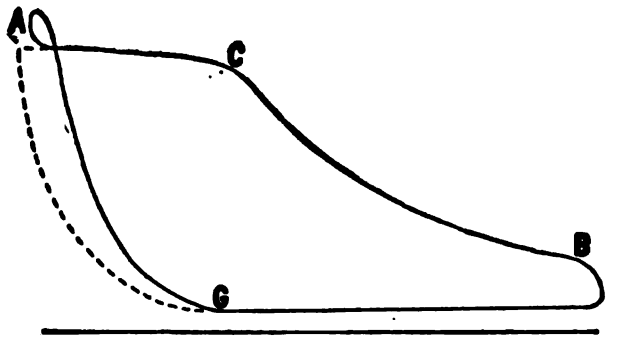


Fig. 39.

puting the I. H. P. If the cut off is kept the same and the compression made what it should be, the gain in area would be the area included between the full line and the dotted line plus the area of the loop. The remedy for this case is to decrease the inside lap.

The amount of compression varies with the speed and type of engine. Slow speed engines require *less* compression or cushioning than high speed. The exhaust steam should *never* be compressed higher than the boiler pressure.

For high speed engines the compression should extend to about .9 the initial pressure. For medium speeds about .5 and for low speed .2 to .4.

In the case of a slide valve engine it is not always possible to set the valve so that the card may have all the events as they should be. Sometimes the laps of the valves should be altered. For too much compression decreases the inside lap. For too early cut off decrease the outside lap.

If the valve travel is increased, compression is retarded, that is, decreased; release occurs sooner.

STEAM CONSUMPTION.

The amount of steam used by an engine is called its **steam consumption** and for comparison, it is customary to state the amount of steam consumed per indicated horse-power per hour. By means of the indicator diagram the steam consumption can be computed approximately.

To find the Steam Consumption from the Diagram. The diagram shown in Fig. 40 is from a 20 × 36 engine, running at a speed of 80 revolutions per minute. A 40-pound spring was used.

By measuring the card, we find the mean ordinate to be .91 inch and the M. E. P. = .91 × 40 = 36.4 pounds.

I. H. P. = Engine Constant × M. E. P. × piston speed.

= .00952 × 36.4 × 480.

= 166.33.

In Fig. 40 L M is the atmospheric line and O R the line of zero pressure drawn so that O L = 14.7 pounds. O N is the clearance volume = 8 per cent of the piston displacement. The line P Q is drawn from O R to some point on the compression

curve. From D, a point on the expansion curve before release, the line D F is drawn perpendicular to O R.

Then from the diagram,

O R = 3.24 inches.
O F = 3.00 inches.
O P = .345 inch.
D F = .795 inch.
P Q = .795 inch.

The length of stroke is 36 inches or 3 feet, and the length of the diagram 3 inches. Then 1 inch of the length of the card corresponds to 1 foot of the stroke. The scale of spring used is 40. Therefore we can easily reduce the above dimensions to pounds pressure and to feet.

O R = 3.24 feet.
O F = 3.00 feet.
O P = .345 feet.
D F = 31.80 pounds.
P Q = 31.80 pounds.

The area of the piston (head end) is,

$$\frac{\pi d^2}{4} = \frac{3.1416 \times 400}{4} = 314.16 \text{ sq. in.} = 2.18166 \text{ sq. ft.}$$

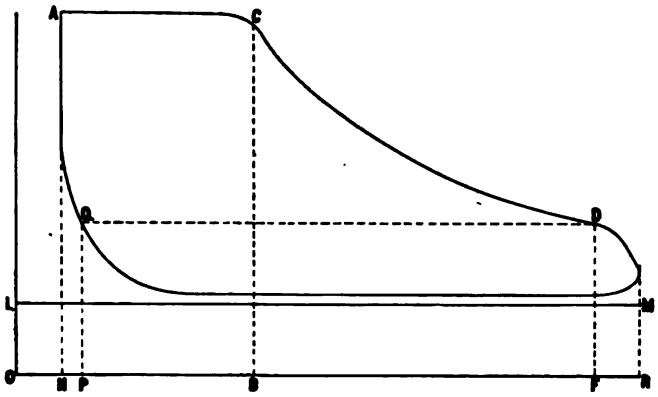


Fig. 40.

We can now find the volume of steam at any point of the stroke.

When the piston is at D, the volume is,

$$2.18166 \times 3 = 6.54498 \text{ cubic feet.}$$

When the piston is at Q, the volume is,

$$2.18166 \times .345 = .75267 \text{ cubic foot.}$$

From the steam tables we can find the weight of a cubic foot of steam at a given pressure.

The weight of 1 cubic foot at 31.8 pounds absolute pressure is .07773 pound. Then the weight of steam present when the piston is at D is,

$$6.54498 \times .07773 = .50887 \text{ pound.}$$

The weight of steam present when the piston is at Q is

$$.75267 \times .07773 = .05852 \text{ pound.}$$

The weight of steam in the cylinder is .50887 pound and the weight of steam kept for compression is .05852 pound. The weight exhausted per stroke is,

$$.50887 - .05852 = .45035 \text{ pound.}$$

The amount used per I. H. P. per hour is,

$$\frac{.45035 \times 2 \times 80 \times 60}{166.33} = 25.993 \text{ pounds.}$$

This may be stated in words as follows:

Measure the pressure from the vacuum line to some point in the expansion curve before release and from the steam tables find the weight of a cubic foot at that pressure. Multiply the volume (in cubic feet) of the cylinder, including clearance to that point, by the weight per cubic foot. The result is the weight of steam in the cylinder. As this weight includes the steam used for compression it must be corrected to obtain the weight used per stroke.

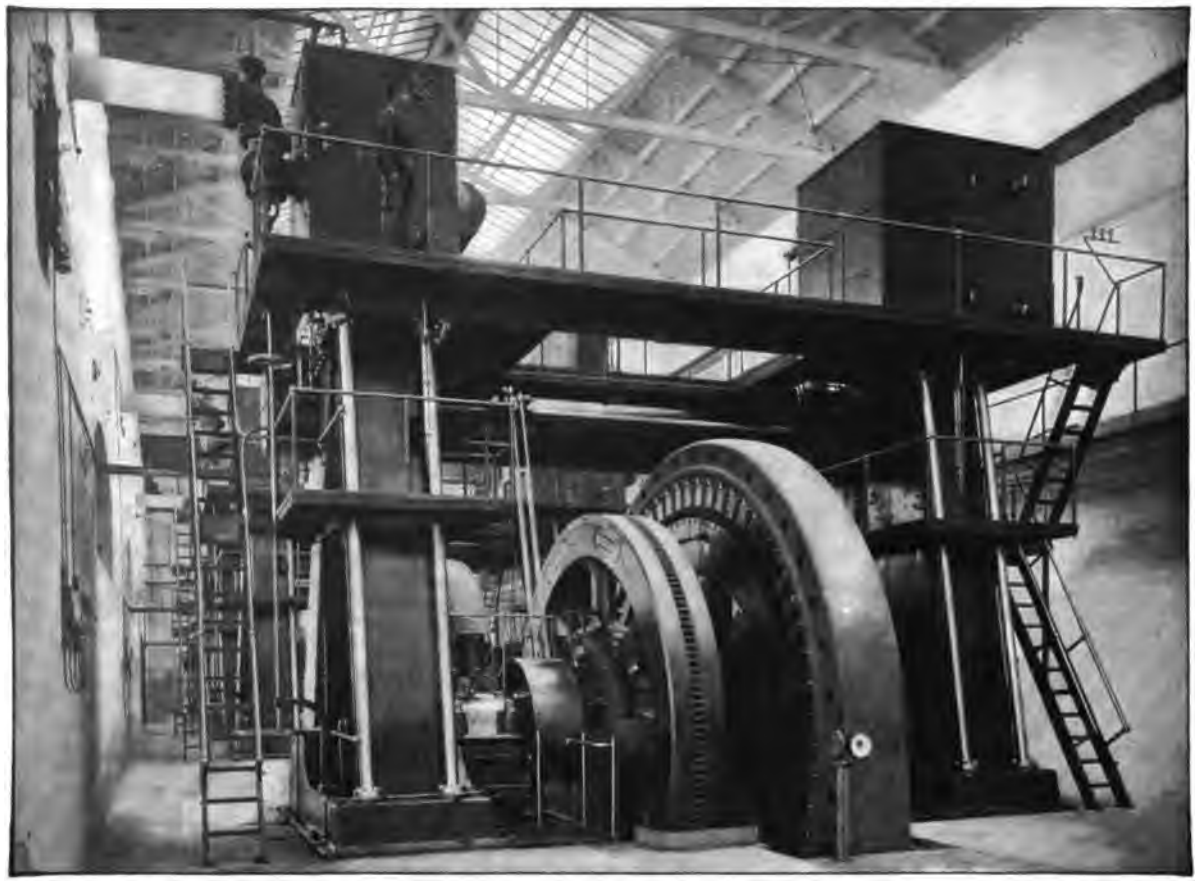
Take some point on the compression curve and measure its absolute pressure. Then compute the weight of steam to this point. Subtract this weight from the weight of steam to the point in the expansion curve and the result is the weight of steam used per stroke.

Multiply the weight of steam used per stroke by the number of strokes and divide by the indicated horse-power as found from the card. The final result is the number of pounds of steam consumed per horse-power per hour.

We may also calculate the steam consumption by taking the point of the expansion curve near the cut-off.

O B = 1.23 inches = 1.23 feet of the stroke.

B C = 1.8 inches = 72 pounds.



2400 Horse-power Cross-compound Engine, with Direct-driven Multiphase Electric Generator.
(Courtesy of McIntosh, Seymour & Co.)

The weight of 1 cubic foot of steam at 72 pounds absolute pressure is .1671 pounds. Then the volume of steam at C is,

$$2.18166 \times 1.23 = 2.68344 \text{ cubic feet.}$$

The weight at C is,

$$2.68344 \times .1671 = .44840 \text{ pound.}$$

The weight kept for compression is the same as previously found, *i. e.*, .05852 pound.

Then the weight of steam used per stroke is,

$$.44840 - .05852 = .38988 \text{ pound.}$$

The steam consumption per I. H. P. per hour is,

$$\frac{.38988 \times 2 \times 80 \times 60}{166.33} = 22.50 \text{ pounds.}$$

If the valve doesn't leak, the amount of steam just after cut off should equal the amount just before release, but our calculation shows that there is .45035 — .38988 = .06047 pound more at release than at cut off. This shows that at entrance .06047 pound was condensed before the piston reached C and was re-evaporated before release. This calculation gives an idea of the amount of cylinder condensation.

If there is considerable compression as in Fig. 40 the above method may be simplified by taking the two points D and Q at the same height above the vacuum line. The pressures will then be the same.

Let W = weight of steam used per I. H. P. per hour.
w = weight of one cubic foot of steam at the absolute pressure D F.
L = length of the diagram, N R.
l = distance between Q and D.
P = mean effective pressure.

Then,

$$W = \frac{13{,}750 \times w \times l}{P\ L}.$$

Example. A card was taken from a 12 × 14 engine. Length of card L = 3.5 inches, l = 2.875 inches. Absolute pressure at

D = 30 pounds. M. E. P. = 30.75 pounds. What is the steam consumption per I. H. P. per hour?

$$W = \frac{13{,}750\ w \times l}{P \times L}$$

$$= \frac{13.750 \times .0736 \times 2.875}{30.75 \times 3.5}$$

$$= 27.03 \text{ pounds.}$$

This method gives only an approximate steam consumption. On account of the leakage of valves and the initial condensation of steam in the cylinder, the actual consumption is somewhat greater. The excess varies considerably and makes all results so obtained of little value. In our calculation we used one diagram only, that for the head end; we assumed the diagram from the crank end to be the same. The indicated horse-power for each end should be computed, as it is subject to considerable variation. In the above formula the average mean effective pressure should be used. The results of calculations of steam consumption from indicator cards are so unreliable that engineers place little dependence upon them. The results may be used as a basis for estimates, but for accurate knowledge, an engine test must be resorted to.

EXAMPLES FOR PRACTICE.

1. Given the following data to find the M. E. P. Area of card 2.79 square inches, length of card 3.1 inches, scale of spring 50. Ans. 45 pounds.

2. Steam enters a cylinder at a pressure of 210 pounds by gage and leaves at 3 pounds pressure (absolute). What is the thermal efficiency? Ans. 29 per cent.

3. An engine has a B. H. P. of 78.96. The I. H. P. is 86.73. What is the mechanical efficiency. Ans. 91 per cent.

4. An engine develops 149.97 I. H. P. If the piston diameter is $17\frac{3}{4}$ inches, the stroke 30 inches, and the M. E. P. 40 pounds, what is the speed? Ans. 200 revolutions per minute.

5. The theoretical M. E. P. of a triple expansion marine engine is 48 pounds. What is the probable actual M. E. P.?

750 HORSE-POWER TANDEM-COMPOUND ENGINES, BUILT BY McINTOSH, SEYMOUR & CO.,
With Direct-Driven Electric Generators.

SECTION 5.

VALVE GEARS.

The valve gear of a steam engine consists of the valve or valves that admit steam to and exhaust it from the cylinder, and the mechanism which gives motion to the valves.

Engines are classified according to the work they are to do, as **stationary, marine,** etc.; the arrangement of the cylinders as, **simple, compound,** etc.; and according to the kind of valves as, **plain slide, Corliss,** etc. Engines thus classified may be *condensing* or *non-condensing*, *vertical* or *horizontal*, *single* or *double acting*.

In most engines the valves receive motion from one or more eccentrics. The simplest valve gear is of the plain slide type with one eccentric. This valve both admits and exhausts the steam. We will discuss this type first, because it is the most common and readily understood; also because the principles involved are followed in the more complicated valve gears.

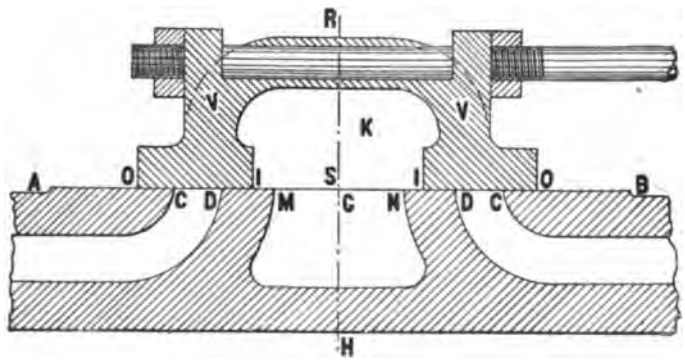


Fig. 1.

Fig. 1 shows the section of an ordinary **slide valve,** with the ports, bridges, etc. It is placed in mid-position in order that the explanation of lap may be more easily understood.

The valve V consists of a hollow box with projecting ends. The lower face is planed and fitted on the plane surface A B called

the **valve seat,** so that it is steam tight. The valve slides back and forth on this seat, opening and closing the ports.

Steam enters the cylinder when either **port** C D or D C is uncovered; it is released when one of these ports is placed in communication with the exhaust port by means of the hollow arch K.

The portions between the exhaust port and the steam ports support the valve and are called the **bridges.**

In most valves the portions O I, which rest on the seat, are broader than the steam ports which they cover. The extra width is called the **lap** and is divided into the **outside lap** O C and the **inside lap** D I. It is seen readily from Fig. 1 that the width O I

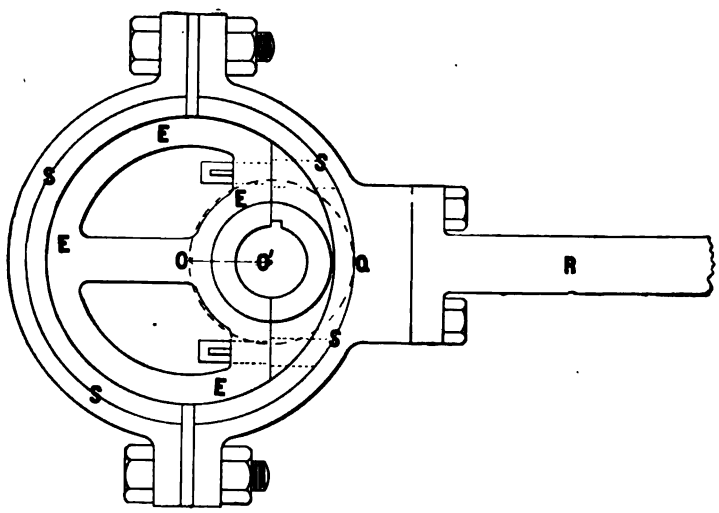


Fig. 2.

equals the sum of the width of the steam port, the outside lap, and the inside lap, or,

$$O\,I = C\,D + O\,C + D\,I.$$

The valve is in **mid-position** when the center line of the valve coincides with the center line of the exhaust port or in Fig. 1 when R S coincides with G H.

The Eccentric. The valve is generally moved by means of an eccentric which is fastened to the shaft of the engine. The eccentric is equivalent to a crank whose radius is equal to the throw of the eccentric or eccentricity as it is sometimes called.

Fig. 2 shows the ordinary form of eccentric. O′ is the center of the crank shaft and O the center of the eccentric. It is evident that if the eccentric E is keyed to the shaft, the point O will describe a circle represented by the dotted line, for every revolution of the shaft. Then the movement is the same as that of a crank keyed to the shaft and having the center of the crank pin at O. The distance O O′ is the **crank radius** or the **throw** of the eccentric. The distance O Q, the diameter of the circle described by the center of the eccentric, is equal to twice the throw of the eccentric and represents the **travel** of the valve.

The **eccentric strap** S which encircles the eccentric E, is connected to the eccentric rod R. This rod is connected to the valve rod by methods varying for different engines.

The back and forth motion of the piston causes the shaft to rotate. The eccentric is fastened to the shaft and causes the valve

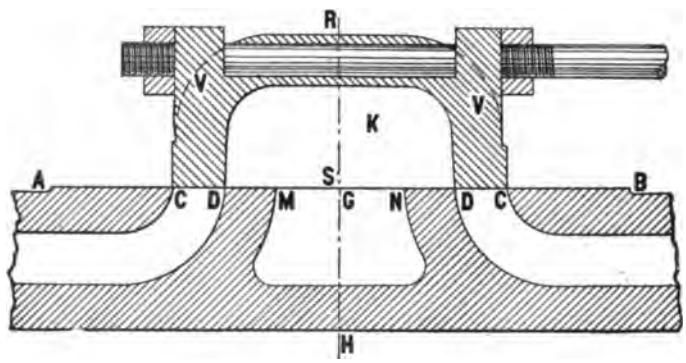


Fig. 3.

to move backward and forward. Thus, to determine the manner in which the slide valve distributes steam to the cylinder, the **relative** positions of the *eccentric* and *crank* must be studied.

The Valve Without Lap. If the plain slide valve is so formed that when in mid-position it does not overlap the steam ports it has no lap. This is the most simple form of valve and is shown in section in Fig. 3. We see by the figure that the portions of the valve which rest on the seat are of the *same* width as the steam ports which they cover when in mid-position.

Any movement of the valve to the right or left admits steam to one end of the cylinder and exhausts it from the other end. In

this case, *admission* continues during the whole stroke and *exhaust* occurs during the same length of time. Since steam is admitted and exhausted during the whole stroke, there is no expansion or compression. The theoretical indicator card for these conditions is a rectangle and the M. E. P. is equal to the initial pressure.

The diagram of an engine having a valve without lap or lead

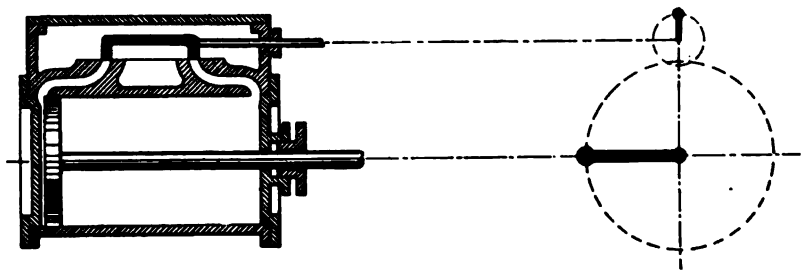


Fig. 4.

is shown in Fig. 4. The piston is at the *beginning* of the stroke and the valve is in *mid-position*. The crank is horizontal and since the valve is in mid-position the eccentric must be set so that the eccentric radius is vertical or at right angles to the crank. When the valve moves toward the right steam is admitted

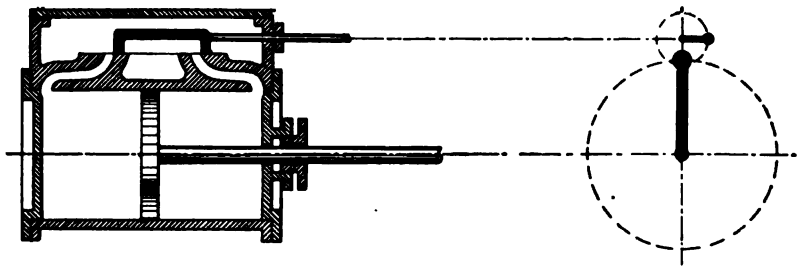
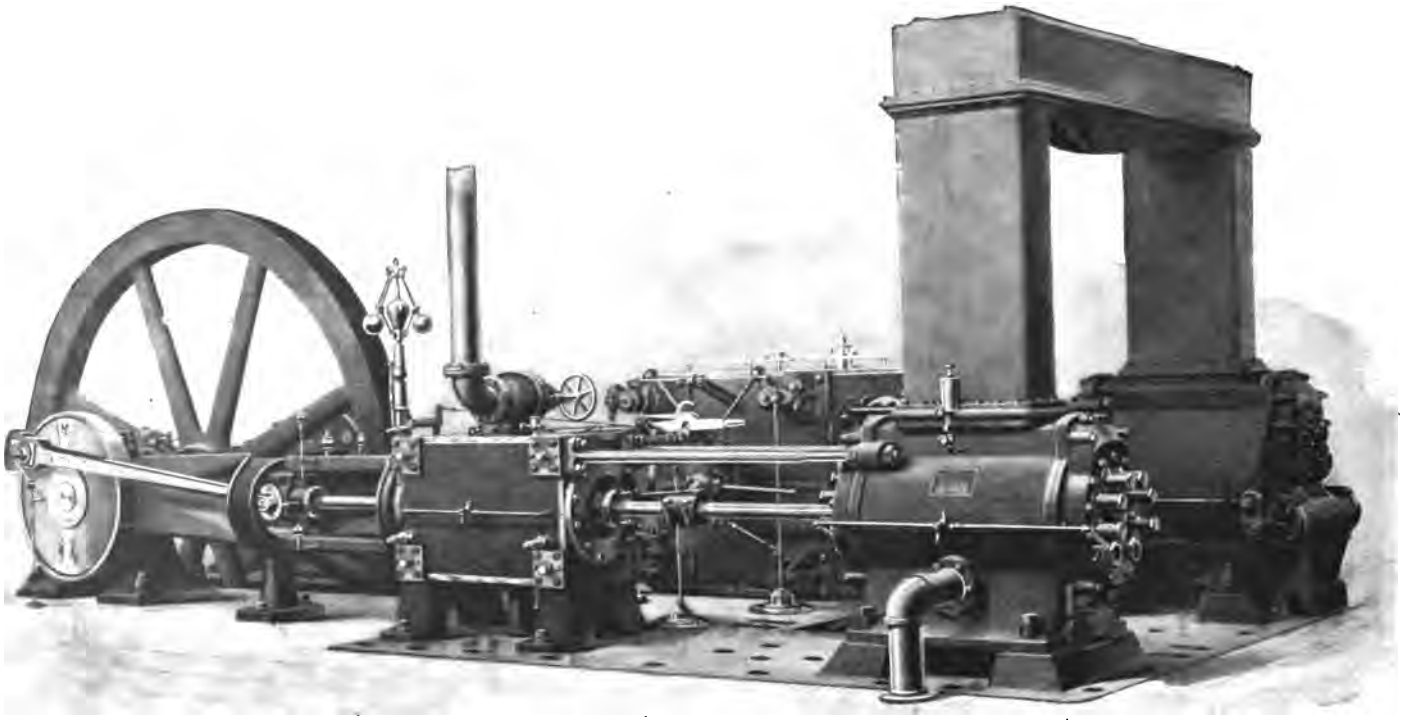


Fig. 5.

to the left hand port and the piston is forced toward the right.

Fig. 5 shows the parts when the crank has made a quarter turn or the piston has moved one half of the stroke. During this time the piston has moved from the end to the middle of the cylinder; the valve has moved toward the right, the left hand steam port is wide open, and the right hand end of the cylinder is



RAND-CORLISS AIR COMPRESSOR

in communication with exhaust. The crank has moved from a horizontal to a vertical position and the eccentric radius and the crank are still at right angles.

Still further movement brings the piston to the right hand end of the stroke and the valve back to mid-position as shown in Fig. 4.

Thus we see that with a valve having no lap or lead, the valve is in mid-position when the piston is at either end of the cylinder and the valve is at the end of its travel when the piston is at the middle of the cylinder. Steam is therefore *admitted* and *exhausted* during the **whole stroke** and there is consequently *no expansion or compression.*

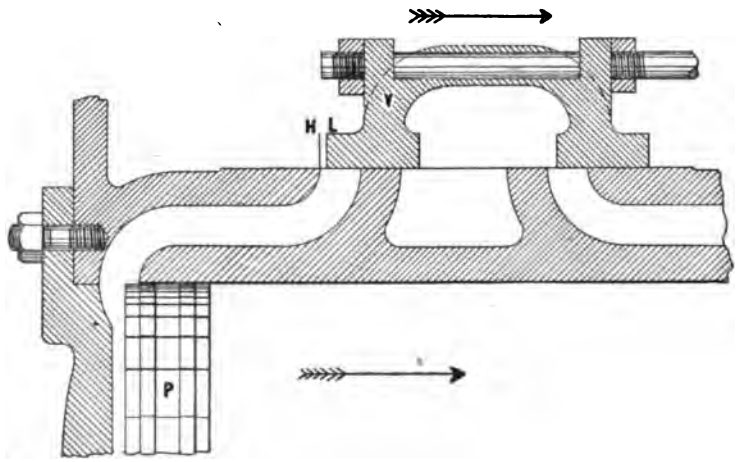


Fig. 6.

The Valve with Lap and Lead. Fig. 1 shows a valve having both inside and outside lap. A valve is said to have **lead** when it begins to uncover the steam port *before* the piston is at the end of the stroke; or, the port is slightly open when the piston is at the end of the stroke. The amount of lead is the distance between the edge of the valve and that edge of the steam port from which it is traveling. Fig. 6 shows the section of a slide valve having lead. The piston P is at the end of the stroke and the steam port is open the amount of the lead H L. That is, when the piston is at the beginning of the stroke, steam can enter the port through an opening of an area equal to the width of the

steam port multiplied by the lead. Valves are given lead in order that the clearance may be filled with live steam when the stroke begins. The lead is usually greater for high speed engines than for low.

In order to use the steam *expansively* the valve must keep the steam ports closed during a *part* of the stroke. For this purpose the valves are given outside and inside lap. With a valve of this kind, steam is admitted when the valve has moved from its mid-position a distance equal to the outside lap and continues until the valve returns to the same distance from its mid-position. Similarly exhaust begins when the valve has moved from the mid-position a distance equal to the inside lap and continues until the valve has again returned to this distance from the mid-position.

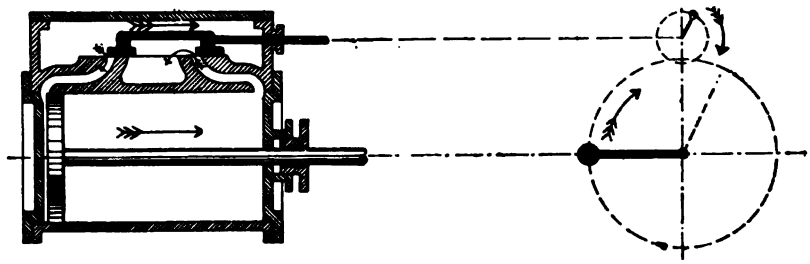
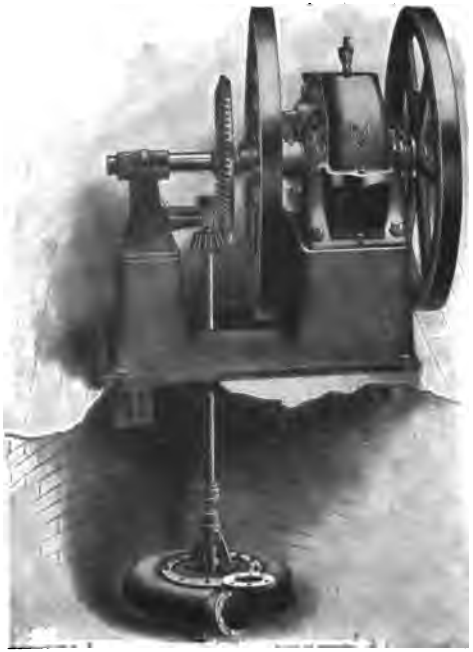


Fig. 7.

Fig. 7 represents the piston just beginning the forward stroke. The valve has opened the left hand steam port an amount equal to the lead. The crank is, of course, in its horizontal position. The eccentric radius is not perpendicular because the valve has moved from the mid-position an amount equal to the outside lap plus the lead. This causes the eccentric radius to form an obtuse angle with the crank. In Fig. 8, the valve and piston are in the same positions as in Fig. 7. If there were no lap the eccentric radius would be vertical or in the position O L. In order to have the edge of the valve coincide with the edge of the port, the valve must be moved a distance equal to the outside lap and consequently the eccentric would occupy a position as shown at O A. This angle L O A is called the angular advance of the eccentric. The angle A O A′ is called the **angle of lead.** The angle of advance plus the angle of lead plus 90° equals the angle between the crank and the eccentric, or,



Vertical Pump Geared to Gas Engine.

Pump with Standard Engine.

Pump with Special Engine.

angle L O A + *angle* A O A′ + 90° = *angle* A′ O R

Referring again to Fig. 7. While steam is entering the cylinder by the left hand port, the piston is driven to the right; the valve also moves to the right. Steam is exhausted from the cylin-

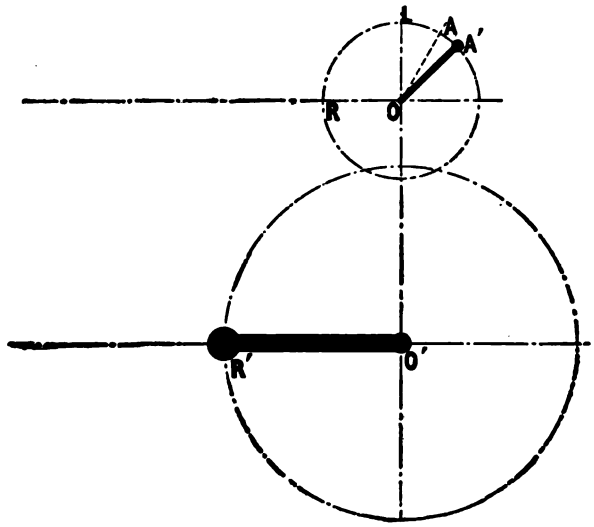


Fig. 8.

der because the right hand end is in communication with the exhaust port.

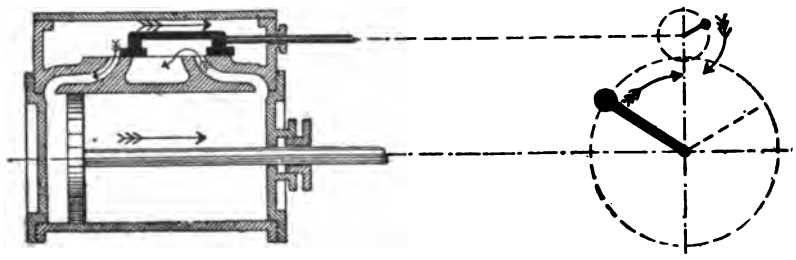


Fig. 9.

In Fig. 9 the valve has moved so that the steam port is wide open and the piston has traveled to the position indicated. Steam is still being exhausted from the other end. The crank has moved from the horizontal and the eccentric radius is approaching the horizontal position.

When the eccentric radius is horizontal the valve is in its *extreme position* or it is at the **end** of its travel. Further movement of the piston causes the valve to move toward its mid-position. Fig. 10 shows the valve returned so that the steam port is *wholly* and the exhaust port *nearly* closed. This closing of the steam port is an important event in the stroke; it is the **point of cut-off.**

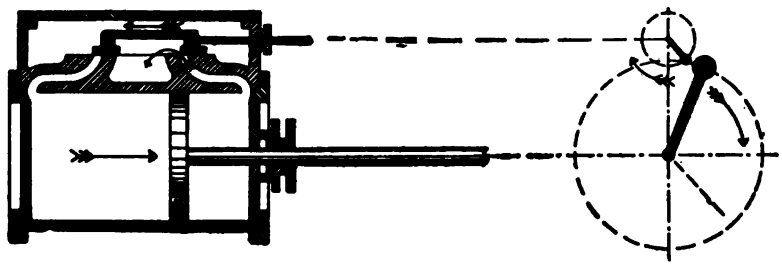


Fig. 10.

Fig. 11 shows the piston and valve moving in the same direction as in Fig. 10. The valve has closed the communication to both exhaust and live steam and therefore the steam at the left **expands** while steam at the right of the piston is **compressed** as

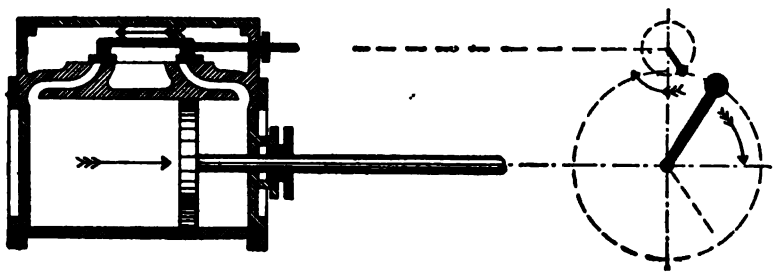


Fig. 11.

the piston moves. The closing of the exhaust is the point where *compression begins.*

The next event is that of **release,** that is, the left hand steam port opens to exhaust and the steam which has been expanding during the forward stroke is exhausted during the backward stroke. Fig. 12 represents the valve on the point of opening the left hand end of the cylinder to exhaust. Compression is still going on in the right hand end.

The piston continues to move to the end of the stroke compressing the steam in front of it until the valve opens to live steam. Then the piston commences the return stroke and the valve is in the same position as in Fig. 7, except that the right hand port is opening to steam instead of the left hand port.

By referring to the figures explaining the movements of the slide valve having lap and lead, we can see the **effects of the lap.**

In Fig. 10 if the outside lap had been greater, cut-off would have occurred earlier because in moving toward the left the greater lap would have caused the port to be closed sooner. The steam from the steam chest would have been cut off before the piston reached the position shown in Fig. 10.

If the outside lap had been less, steam would have been

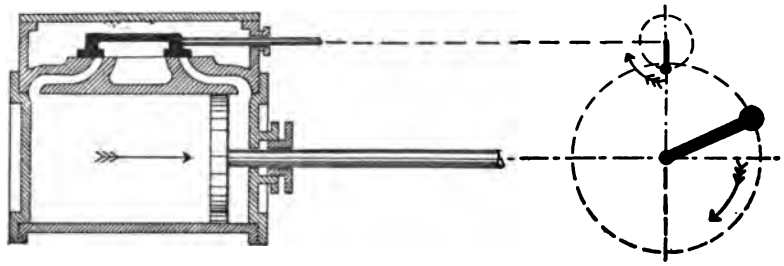


Fig. 12.

admitted earlier and cut-off later, causing less expansion and a higher pressure at release.

By referring to Fig. 11 we can see the effects of increasing the inside lap. The piston is moving toward the right and the valve toward the left. If the inside lap had been greater the valve would have closed the right hand steam port before the piston had reached the position shown in Fig. 11. That is, compression would have commenced earlier. Also with a diminished inside lap, exhaust begins earlier. The beginning of exhaust is generally called release.

If we keep the angular advance the same, *increasing* outside lap causes an *earlier* cut-off and **more complete expansion,** while a diminished outside lap means later cut-off and less expansion.

Increasing the inside lap, causes **greater compression** and **later release,** while decreasing the inside lap decreases compression and makes release earlier.

Thus we see that the *outside* lap influences **cut-off** and **expansion** and that *inside* lap controls **release** and **compression.** For these reasons the outside lap is often called the *steam lap* while the inside lap is called the *exhaust lap.* The outside lap has nothing to do with compression and varying the inside lap does not effect the expansion.

The following table shows the effect of changing the lap, travel and angular advance.

	Increasing Outside Lap.	Increasing Inside Lap.	Increasing Travel.	Increasing Angular Advance.
Admission.	Is later. Ceases sooner.	Not changed.	Begins earlier. Continues longer.	Begins earlier. Same period.
Expansion.	Is earlier. Continues longer.	Beginning unchanged. Continues longer.	Begins later. Ceases sooner.	Begins earlier. Same period.
Exhaust.	Unchanged.	Occurs later. Ceases sooner.	Begins earlier. Ceases later.	Begins earlier. Same period.
Compression	Begins at same point.	Begins sooner. Continues longer.	Begins later. Ceases sooner.	Begins earlier. Same period.

We can now give the following definitions of the parts and positions of the valve.

The outside lap is the amount the edge of the valve overlaps the outside edge of the steam port when the valve is in mid-position.

The inside lap is the amount the edge of the valve overlaps the inside edge of the steam port when the valve is in mid-position.

Lead is the amount the port is open when the piston is at the beginning of the stroke.

The **throw** of the eccentric is twice the distance from the center of the shaft to the center of the eccentric.

The **travel** of the valve is the distance the valve moves back and forth during one stroke of the piston. The travel of the valve is equal to the throw of the eccentric.

Rocker arms. Sometimes it happens that the eccentric cannot be placed on the shaft so that the valve-stem and eccentric rod shall be in the same straight line.

When the valve is placed on top of the cylinder, the valve

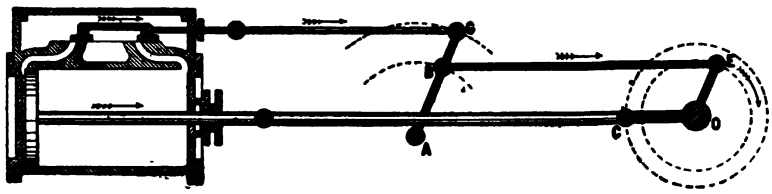


Fig. 13.

seat may be inclined, or a lever called a *rocker arm*, may be employed. It is now uncommon to use the inclined valve seat.

Frequently the valve travel is so great that if the eccentric were made to have the proper throw, it would be too large. By means of a rocker arranged as shown in Fig. 13, the seat may be

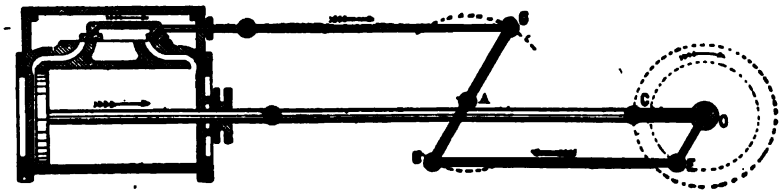


Fig. 14.

in any position, and a smaller eccentric used. In these figures the radius of the eccentric is exaggerated. The direction of motion of the valve and eccentric is the same as shown in Fig. 7; the throw of the eccentric is less than the travel of the valve.

In case it is more convenient to place the pivot of the rocker arm *between* the connections to the valve stem and those of the eccentric rod, the arrangement shown in Fig. 14 is used. Then the eccentric radius is moved 180° so that the valve will move in the proper direction. If the eccentric is not shifted, the engine will move in the opposite direction.

To find the throw of the eccentric, when a rocker arm is used, it is necessary to know the ratio of A B to A G. In either case the throw of the eccentric is less than the valve travel by the ratio A B to A G. Thus if the valve travel is $4\frac{1}{2}$ inches, A B is

15 and A G is 18 inches, the throw of the eccentric will equal $4\frac{1}{2} \times \frac{15}{18} = 3\frac{3}{4}$ inches.

We can see the amount the crank or the eccentric radius moves from without the engine, but it is not as easy to determine the movement of the piston and valve. However this can be done by diagrams.

The eccentric rod is usually long; the length is so great that the motion of the valve is about the same as though the eccentric rod were of infinite length.

We can draw a circle, Fig. 15, to represent the path of the eccentric center during one revolution of the engine. Then in

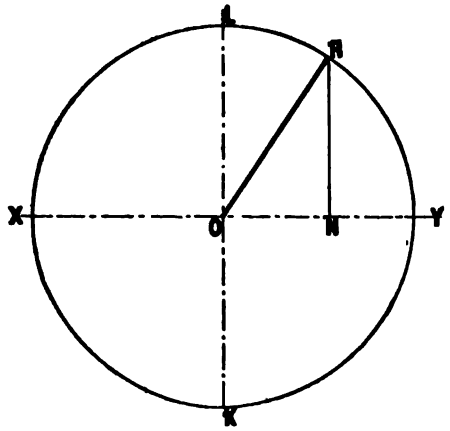


Fig. 15.

Fig. 15 the diameter X Y represents the travel of the valve. If we represent the position of the eccentric center by a point on the circumference, as R, we can find the distance it has moved from mid-position by drawing a perpendicular from the point to the line X Y. Since the point R would be at L when the valve is in mid-position the movement of the valve is equal to the distance from the center of the circle to the perpendicular R N. Hence if the eccentric center is at R the valve has moved the distance O N from its mid-position.

We could find the position of the crank by the same method as that used to find the displacement of the valve if the connecting rod were of infinite length. In most engines the connecting rod is short, that is, its length as compared with the length of stroke

is small. For this reason, the events of the stroke are not the same for both ends of the cylinder if the valve is set for one end. Because of the shortness of the connecting rod, the displacement of the piston is found by drawing a diagram similar to that shown in Fig. 16. X Y represents the stroke, P the piston, H the cross-head, H R the connecting rod, R the crank pin, O the center of the shaft and R O the crank. Suppose the parts are in the positions indicated; then if the connecting rod were of infinite length, the displacement of the piston from the end of the cylinder would be the distance from X to a line from R perpendicular to X Y. To find the true displacement draw an arc of a circle R N through R having its center at H and a radius equal to the length of the connecting rod H R. Then N O equals the displacement from

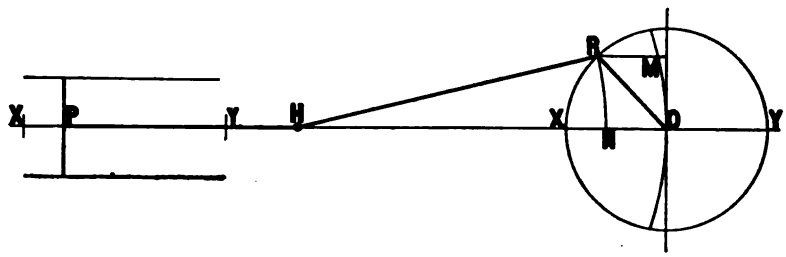


Fig. 16.

the middle of the cylinder or X N equals the displacement from the end. Therefore X N = X P.

Another method is to draw the arc having the same radius, through O instead of through R, and by drawing R M parallel to X Y. R M being equal to N O measures the displacement from the center.

Valve Diagrams. To show, graphically, the events of the stroke determined for given lap, lead, angular advance, etc., valve diagrams are drawn. Let us first draw a circle shown in Fig. 17 whose diameter X Y is equal to the travel of the valve. Then let O N represent the outside lap, O L the inside lap, and through N and L draw lines at right angles to X Y. The points A, C, B, and D mark the positions of the eccentric center when admission, cut-off, release and compression occur at one end of the cylinder. If it is desired to find the corresponding positions for the other

end, the outside lap for that end is laid off to the left of O and the inside lap to the right. In order not to complicate the diagrams we will consider but one end. The circumference of the circle represents the path of the center of the eccentric. Of this circumference the portion from A to C represents the travel during admission and is called the **arc of admission.** Similarly C B is the **arc of expansion,** B D that of **exhaust** and D A that of **compression.**

Suppose the crank occupies the position O X and the eccentric is set in advance of the crank by the angle equal to X O A.

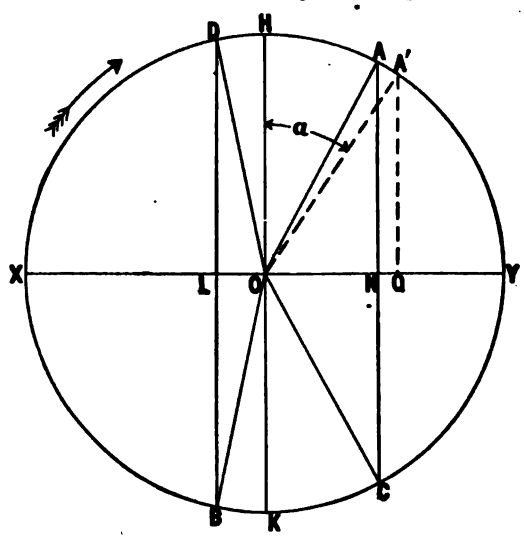


Fig. 17.

Then the valve would open as the stroke begins. In most cases, however, it is desirable that the valve should begin to open *before* the stroke begins, so that the port is partially open at the beginning of the stroke. If the eccentric radius is set in the position O A′ instead of O A the valve will be open the distance N Q called the *lead* when the stroke begins. Then the angle A O H is called the angular advance. The effect of lead is to cause pre-admission, that is, the lead allows steam to enter before the previous stroke is completed. This increases the cushioning. Since displacements are measured on X Y, the greatest opening during admission is N Y. The width of the steam ports is made at least

equal to this distance, usually it is made greater, because of the wide opening L X during exhaust.

This gives us the position of the *eccentric radius* for the four events of the stroke but doesn't show us the position of the *crank*. To determine this we make a diagram like that shown in Fig. 18. It is simply transferring the four positions of the crank which correspond to the points A, C, B, D of the eccentric.

Fig. 18 shows the motion of the crank pin on one scale and the position of the eccentric center on another scale both being the same circle. The diameter X Y represents the stroke of the piston; another diameter is drawn to represent the line H K of Fig. 17. This line H K is turned back through an angle equal to $90° + a$, therefore the angle X O H is equal to a, or the angular advance + the angle of lead. The lines A C and D B are drawn parallel to H K at distances equal to the outside and inside laps respectively.

Then O N = the outside lap,
O L = the inside lap.

This gives us the four points A, C, B, D, as before but turned back through an angle of $90° + a$, as compared with their positions in Fig. 17. Therefore these points show the positions of the crank pin at the four events of the stroke. When the crank is in position O A, admission occurs; when it reaches the position O C, traveling in the direction indicated by the arrow, cut-off occurs. Hence the steam port is open while the crank-pin travels in the arc A C. This diagram is similar to that of Fig. 17; the distance the port is open is found by drawing a line from the position occupied by the crank-pin perpendicular to the line A C. Therefore when the crank is at O X the valve is open a distance equal to X Z. This is the lead, because the piston is at the end of the stroke when in the position occupied by the line O X.

By projecting the points A, C, B, D, on the diameter X Y, using an arc whose radius is equal to the length of the connecting rod, the probable indicator diagram may be drawn.

Inequality of Distribution on Either Side of the Piston. In our valve diagrams thus far we have considered the events of the stroke for one end of the cylinder only. We have used the head end.

If the connecting rod of an engine were of infinite length, and therefore always remained parallel to the center line of the engine, the distribution would be the same for both ends of the cylinder. In practice, however, the connecting rod is usually 4 to 8 times the length of the crank. This causes the cut-off to be considerably earlier at the back than at the front end.

In Fig. 19 the lines X Y, H K, A C, and B D are drawn as in Fig. 18. The line A C represents the outside lap at the back

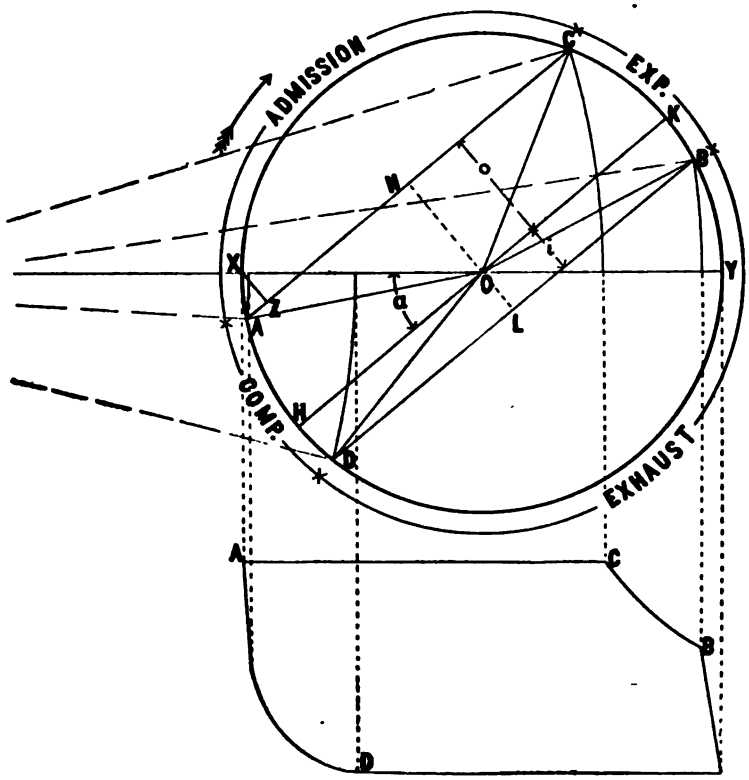


Fig. 18.

end and is drawn so that O N equals O'N', or the lap at the front end is the same as that at the back.

We know from Fig. 16 that M C is equal to the distance that the piston has passed mid-stroke when cut-off occurs at the front end. Then M' C' equals the distance that the piston has traveled from mid-stroke when the cut-off occurs at the back end. M C is

longer than M′ C′ and cut-off is earlier at the back than at the front end.

In a similar manner it may be shown that compression is not symmetrical.

In case the connecting rod is long, this inequality is slight but is important when the connecting rod is short as in high-speed engines and in most marine engines.

If the eccentric rod is short the perpendicular lines from the circumference to the diameter should be arcs of a circle instead of straight lines as shown in Fig. 17. Usually the eccentric rod may be considered as of infinite length.

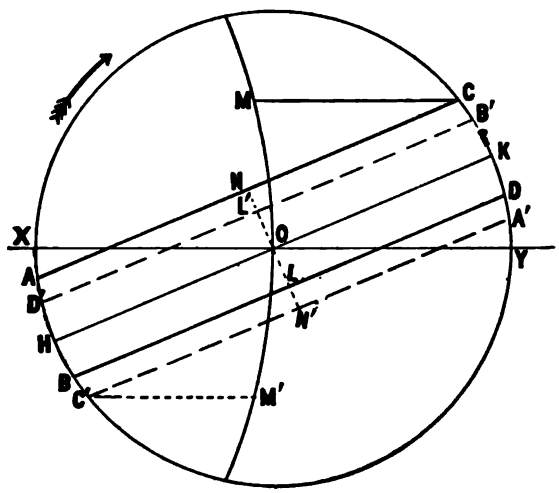


Fig. 19.

We have seen how with a short connecting rod there is unequal distribution if the lap is the same for both ends. By adjusting the lap, making it unequal for the two ends, the point of cut-off may be made equal for **both ends** of the cylinder. In Fig. 20, X Y and H K are drawn as before. The arc M O M′ has a radius equal to the length of the connecting rod. N O equals the outside lap for the head end. Then A C is drawn parallel to H K and at a distance N O from it. Admission occurs when the crank is in the position O A and cut-off when in the position O C. Then as before M C equals the displacement from mid-position when cut-off occurs. To have equal cut-off draw C′ M′ equal to C M and

through C′ draw C′ A′ parallel to H K. Then for equal cut-off N O is the outside lap of the front end and N′ O the outside lap for the back end. In the same way the inside laps may be adjusted to give equal compression. From Fig. 20 it is seen that although cut-off is the same, the lead for the front end is much less than for the back end. The lead is greatly increased by reducing the outside lap.

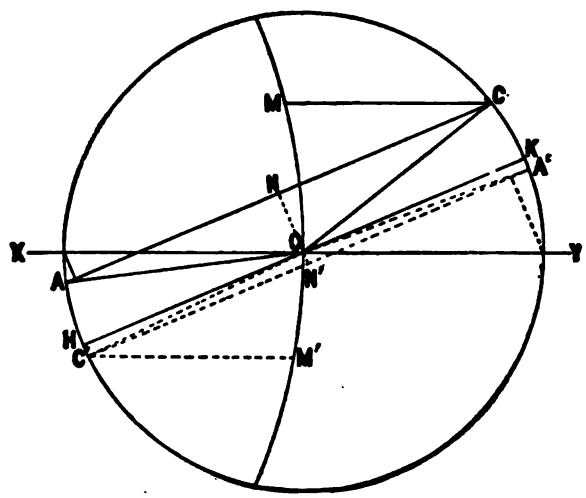


Fig. 20.

THE ZEUNER VALVE DIAGRAM.

The mathematical calculations for the dimensions of the slide valve, the throw of the eccentric and the distribution of steam are too complicated to be generally used. In place of mathematics various diagrams have been designed; the Zeuner diagrams are the best and the most used.

In order that the following diagrams may be as simple as possible, we assume the connecting rod to be of infinite length. The diagrams thus made show the positions of the crank when the events take place; the *true* positions of the piston may be found for the forward and backward strokes if the ratio of the length of the connecting rod to the length of the crank is known.

As in previous diagrams the line X Y of Fig. 21 represents the travel of the valve. The line E O F is then drawn at an

angle to X Y equal to 90° plus the angular advance *a*. On the lines E O and F O circles are drawn called valve circles. The diameters of these circles are equal to half the valve travel.

If the valve has *no lap* or *lead* the diagram is very simple; but as almost all valves have lap and lead we will draw the diagram with these indicated.

To indicate lap, mark off O N on E O equal to the outside lap and draw the arc V N K having its center at O and a radius O N equal to the outside lap; also make O L equal to the inside lap and draw the arc Q L P.

To find the position of the crank at admission draw the line

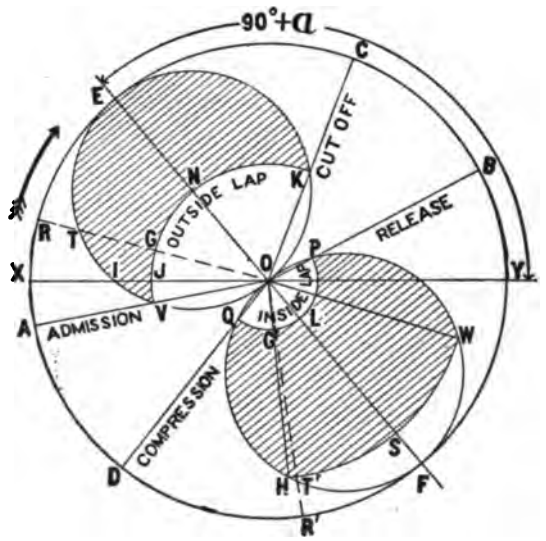


Fig. 21.

A O from O to the circumference passing through the point V where the lap circle V N K cuts the valve circle E K O. The position of the crank when cut-off occurs is found by drawing the line O C through K, the point where the valve circle and the lap circle intersect. Similarly the positions of the crank for release and the beginning of compression are the lines O P B and O Q D respectively. When the crank is in any position we can determine the amount the valve is open. It is the distance between the arc of the *lap circle* and the *valve circle* measured along the radius.

Thus, when the crank occupies the position O A, admission occurs because these arcs intersect. When the crank traveling in the direction of the arrow, reaches O X, the piston is at the beginning of the stroke because X and Y represent the positions of the crank pin at dead centers. Then at the beginning of the stroke the port is open the distance I J and I J is, from the definition, the lead. The angle X O A is called the angle of lead or **angular lead.** As the crank moves from dead center to O R the port is opened wider; when the crank-pin has reached R the port is open a distance equal to T G, and when it is at E it is open a distance equal to E N. The opening at this point is called **maximum port opening** because it has gradually opened while the crank-pin has traveled from A to E and at E is wide open; from E to C it gradually closes. When the crank comes to the position O C, cut-off occurs since there is no distance between the arcs at the point K. From O C to O B the port is closed and therefore expansion takes place.

When the crank-pin reaches B the valve opens the port to exhaust. From this point to F the exhaust port opens wider and wider, until it reaches its maximum opening at F. At this point, the maximum port opening is L S because L S represents the whole width of the steam port. From the diagram it will be noticed that the steam port is open full port but an instant, and then only when the crank is at O E. The exhaust port is open full port while the crank is moving from O W to O H. When the crank-pin is at R′ the exhaust port is open a distance equal to G′ T′. On reaching D the exhaust port is closed and compression begins.

Compression continues until the crank-pin reaches A; at this point live steam is admitted as already explained.

All the problems on valve gears involve relations between certain **variable quantities** which are,

The valve travel.

The angle of advance and angle of lead.

The inside and outside laps of the valve.

The points of the stroke at which admission, cut-off, release and compression take place.

In designing, a few of these variables must be assumed, or depend upon the size of the engine. For instance, we often assume the travel of the valve, the point of cut-off and the lead. Knowing these facts we can find the dimensions of our valve by means of a Zeuner valve diagram.

To fix these principles, we will consider a few practical problems.

One of the simplest problems is the following:

Given the travel of the valve = 6 inches
Angular advance = 45 degrees
Angular lead = 6 degrees
Compression = .7 stroke

To determine the remaining variables, or to find:

The positions of the crank, for admission, cut-off, release and compression.

The laps of the valve.

The linear lead.

Let us consider the connecting-rod of infinite length. First, we draw a line X Y, Fig. 22, equal to the valve travel, *i. e.*, 6 inches. Fig. 22 is drawn to scale $1'' = 2''$. Now describe a circle having the valve travel as a diameter. O M is drawn from the center of the circle perpendicular to X Y. Then the line E F is drawn through O at an angle of 45 degrees to O M. Since the crank travels in the direction indicated by the arrow the angle E O M is measured to the right of O M. In the previous figures, the piston has traveled in the opposite stroke and the angle laid off to the left of O M.

Now the angle E O M is the angular advance; therefore on E O and O F we can draw our valve circles as indicated in Fig. 22. As the angular lead is 6 degrees we lay off O A forming an angle of 6 degrees with X Y. Then A is the point of admission.

The line O E indicates the position of the crank when the port is wide open. Then as it commences to open when the crank is at O A, and is wide open when at O E, it will be closed again when the crank has moved from O E through an angle equal to the angle A O E. Therefore we lay off the angle E O C equal to the angle E O A. Hence C is the position of the crank-pin when the port is again closed or the point of cut-off.

To find the position of the piston when cut-off occurs we

draw C C′ perpendicular to X Y. Then to find the per cent. of stroke at which cut-off occurs we divide C′ Y which in this case is 3.3 inches by the length of the line X Y which represents the stroke. Thus cut-off occurs at $\frac{3.3}{6} = .55 = 55$ per cent. of the stroke.

To find the outside lap we draw an arc, V K, with O as the center and a radius such that the arc passes through the point K

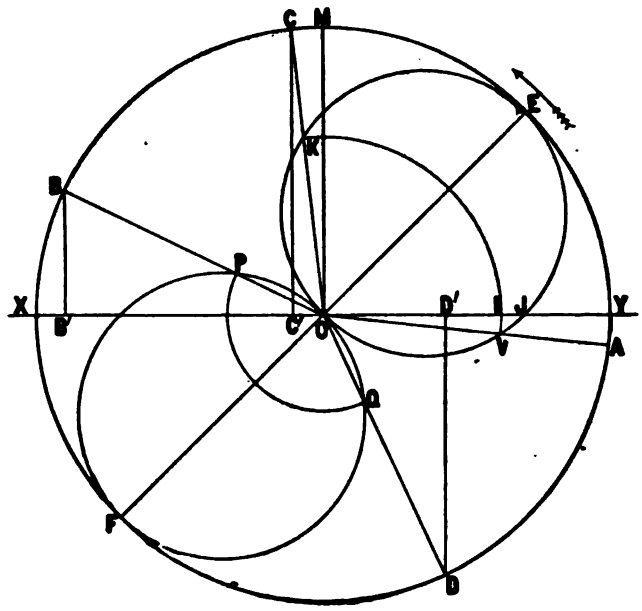


Fig. 22.

where the valve circle intersects the line O C. From Fig. 22 we find this lap to be $1\frac{7}{8}$ inches.

We can find the linear lead from the diagram; it is the distance I J which equals .24 inch or about $\frac{1}{4}$ inch.

To find the inside lap we use the same process as in finding the outside lap. But in the former case we had the angular advance to aid us in finding the per cent. of the stroke at which cut-off occurs. Now we know the point at which compression begins, namely, .7 of the stroke, so we lay off X D′ = .7 of the stroke X Y. Then we draw D D′ perpendicular to X Y. The point D is the position of the crank-pin when compression begins.

The line D O is drawn from D to the center of the circle. The arc Q P is drawn with a radius such that the arc passes through the point where D O intersects the valve circle. We find the inside lap to be 1 inch. We have now solved the problem and can tabulate the dimensions of the valve.

Travel of the valve	= 6 inches
Angular advance	= 45 degrees
Angular lead	= 6 degrees
The outside lap	= $1\frac{1}{8}$ inches
The inside lap	= 1 inch
The point of cut-off	= .55 stroke
Compression begins	= .7 stroke
The linear lead	= $\frac{1}{4}$ inch

Another problem:

The valve travel	= 5 inches
Cut-off	= .5 stroke
Connecting-rod	= 3 × length of crank
Compression	= .6 stroke
Angular lead	= 10 degrees

To find

Outside lap

Inside lap

Angular advance

Linear lead

As before, we first draw the circle which represents both the travel of the eccentric center and the path of the crank-pin. In this case, Fig. 23 which is $\frac{1}{2}$ size, the diameter X Y is 5 inches.

The connecting-rod is 3 times the length of the crank. Since the line X Y represents the stroke and is 5 inches long, O X represents the length of the crank and is $\frac{5}{2} = 2\frac{1}{2}$ inches long. Therefore the connecting-rod can be represented as being $3 \times 2\frac{1}{2} = 7\frac{1}{2}$ inches long.

To find the position of the crank-pin at cut-off, we draw an arc having a radius of $7\frac{1}{2}$ inches with its center in X Y produced; this arc passes through O since cut-off takes place at .5 of the stroke. The point at which this arc cuts the circle is the position of the crank-pin at cut-off. Then the crank occupies the position C O.

Since the angular lead is 10 degrees the line O A is drawn

forming an angle of 10 degrees with X Y. The reason for drawing this angle on the left side of the center is readily seen from the direction of the arrow, which indicates the stroke.

To find the angular advance E O M we have only to divide the arc C A into the equal parts E C and E A.

Then on the line E O F we draw the valve circles as before. We can now find the outside lap, by drawing an arc with the center at O and having a radius such that the arc passes through

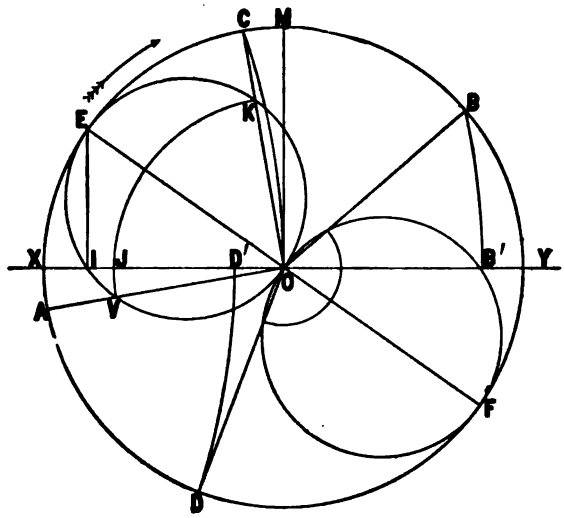


Fig. 23.

K and V; the intersections of the valve circle and the lines indicating the position of the crank at cut-off and admission. From the figure we find the outside lap to be $1\frac{3}{4}$ inches.

Since compression is to begin at .6 stroke we find the inside lap by the same method as in the previous problem, namely, laying off Y D′ = .6 X Y and finding the point D on the circumference of the circle. In the previous problem the connecting-rod being infinitely long we did this by drawing a line from D′ to the circumference perpendicular to X Y. In this problem, however, the connecting-rod is three times the length of the crank, hence we draw with a radius of $7\frac{1}{2}$ inches, the arc D D′ instead of a straight line. The inside lap is found to be .6 inch.

The value of the angle E O M is found by means of a protrac-

tor, or by any method known to the designer. In Fig. 23 it is 56 degrees.

The linear lead I J is $\frac{1}{4}$ inch.

Then the valve will have the following proportions:

Valve travel	= 5 inches
Outside lap	= $1\frac{3}{4}$ inches
Inside lap	= .6 inch
Angular advance	= 56 degrees
Angular lead	= 10 degrees

Cut-off as assumed occurs at .5 stroke and compression begins at .6 stroke. The valve will have a linear lead of $\frac{1}{4}$ inch.

Let us consider a third problem; one in which the valve travel is not known.

Suppose the following variables to be known:

Point of cut-off	= .6 stroke
Linear lead	= $\frac{1}{2}$ inch
Outside lap	= $1\frac{3}{4}$ inches
Inside lap	= $\frac{7}{8}$ inch

To find,

Valve travel.

Angular advance.

Angle of lead.

Beginning of compression.

Let us assume the connecting-rod to be infinitely long.

In the previous problems we had given the valve travel, and we could at first draw the circle having a diameter equal to the sum of the diameters of the two valve circles. In this problem we must proceed differently.

First we measure off on a line any convenient length; for example 8 inches. Then we let this length X′ Y′, Fig. 24 which is $\frac{1}{2}$ size, represent the stroke. As X′ Y′ represents the stroke we measure off X′ R equal to .6 X′ Y′ and then draw R C″ perpendicular to X′ Y′. The line connecting C″ with the center of the circle is the position of the crank when cut-off occurs. We can draw the arc V J K since the outside lap equals $1\frac{3}{4}$ inches. We can also draw the inside lap circle having a radius of $\frac{7}{8}$ inch.

The lead is $\frac{1}{2}$ of an inch. We can measure off I J equal $\frac{1}{2}$

inch. We know from plane geometry that at least three points are necessary to determine the circumference of a circle. Then to draw our valve circles we must know three points on the circumference of one of them. The point K, which is the intersection of the line O C″ and the lap circle is one, the center of the circle O is another and the point I is the third. By geometrical construc-

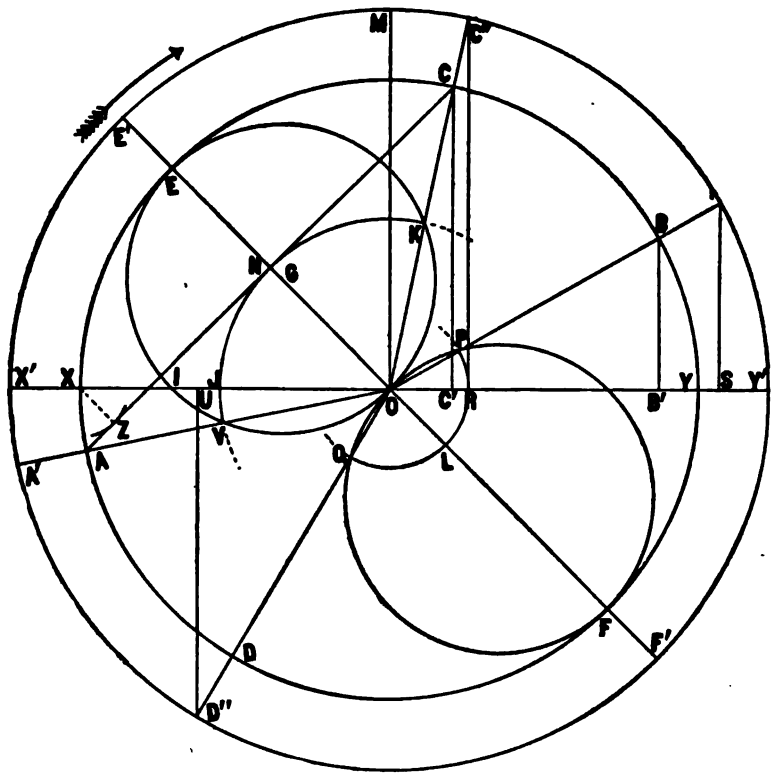


Fig. 24.

tion, a circle can be drawn through these three points with its center at G. The valve circles determine the valve travel, hence the valve travel is E F or $6\frac{1}{2}$ inches. We can draw an arc having X as a center and a radius X Z equal to the lead. Then we can draw the line C N Z A tangent to the arc at Z and the outside lap at N. If we know the center of

the valve circles we can determine the angular advance; it is the angle E O M or in this problem 45 degrees.

To find the beginning of compression we draw O Q D as we have in previous problems. Then we draw D″ U perpendicular to X Y. The point at which compression begins is the same per cent. of the stroke that Y′ U is of X′ Y′. X′ Y′ as before is 8 inches long and Y′ U is 5.92 inches long; therefore compression begins at

$$\frac{5.92}{8} = .74 = 74 \text{ per cent. of the stroke.}$$

The valve diagram now is similar to those already drawn. Not knowing X Y we were obliged to determine it by geometry.

The triangles O C C′ and O C″ R are similar. Then O C : O C″ = O C′ : O R. O C and O C″ are the radii of the circles then X Y : O C′ = X′ Y′ : O R. Also X Y : X C′ = X′ Y′ : X′ R.

In like manner the triangles O B B′ and O B″ S are similar and to find the point at which release occurs, we find the ratio of X B′ to X Y. It is the same as the ratio;

$$\frac{X'\,S}{X'\,Y'} = \frac{7.5}{8} = \frac{6.09}{6.5} = .937 = 93.7 \text{ per cent. of the stroke.}$$

There are many other problems involving the same principles, the above illustrating the methods used in solving them.

DESIGN OF SLIDE VALVE.

In designing a slide valve some of the variables are assumed and the others are found by means of diagrams as we have already seen. These diagrams show only the dimensions of the inside and outside laps and travel of valve; the other dimensions of the valve and seat must be calculated.

Area of Steam Pipe. Pipes that supply the steam chest should be large enough to prevent an excessive loss of pressure due to friction. If the pipes are long they should be of such size that the mean velocity of steam in them does not exceed 100 feet per second or 6,000 feet per minute. For this calculation it is usual to assume steam admitted to the cylinder during the whole stroke.

For example. Suppose an engine is 10″ × 18″, and makes 180 revolutions per minute. What is the diameter of the steam pipe?

The piston displacement or volume of the cylinder is,

$$\frac{\pi d^2}{4} \times l = \frac{3.1416 \times 10^2}{4} \times 18 = 1413.72 \text{ cubic inches}$$

$$\frac{1413.72}{1728} = .818 \text{ cubic feet.}$$

If the engine makes 180 revolutions it would use $2 \times 180 \times .818 = 294.48$ cubic feet per minute.

$$\text{The area would be} = \frac{294.48}{6000} = .04908 \text{ sq. ft.} = 7.0675 \text{ sq. in.}$$

The diameter corresponding to 7.0675 square inches is 3 inches.

A three-inch pipe would be large enough especially if the engine cut-off early in the stroke.

For a very large engine cutting off early, the allowable velocity may be taken as 8,000 feet per minute instead of 6,000 feet.

Width of Steam Port. In the slide valve engine the steam ports admit steam and exhaust it from the cylinder. The steam ports should be large enough to allow a free exhaust with as little back pressure as possible. The low pressure steam, having a greater volume for a given weight, requires a larger passage than the live steam which enters. It is usual to make the width of port greater than the port opening during admission. However, the port opening should be large enough to prevent loss of pressure called wire-drawing. The area of the steam ports should be as great or greater than that of the steam pipe. Experiments show that the allowable velocity of steam through the ports may be 6,000 feet per minute; and a port opening of .6 to .9 the steam port area according to the prevailing conditions gives us free admission.

The length of the ports is usually made about .8 the diameter of the cylinder. Then in the $10'' \times 18''$ engine the steam ports would be 8 inches long. If the area for admitting steam is 7.0675 square inches and the length of port is 8 inches the width will be $= \frac{7.0675}{8} = .8834$ inch or about $\frac{7}{8}$ inch.

The width of port opening would be about $.9 \times .8834 = .79506$ inch or about $\frac{13}{16}$ inch.

Width of Exhaust Port. When the slide valve is at its maximum displacement the valve overlapping the exhaust port reduces the area as shown in Fig. 9. In designing the exhaust port it should be of such a width that the maximum displacement of the valve does not reduce the area of the exhaust port to less than the area of the steam port.

To find the width of the exhaust port add together half the travel of the valve, the width of the steam port and the width of the inside lap; from this sum subtract the width of the bridge. The exhaust port may be made wider if desirable, but if increased very much the valve becomes too large which causes excessive friction.

The height of the exhaust cavity should never be less than the width of the steam port; it is often made once and a half as high or perhaps higher.

Width of Bridge. The bridge must be of sufficient width so that outside edges of the valve cannot uncover the exhaust port. The width of the steam port plus the width of the outside lap plus the width of the bridge must be greater than the maximum displacement.

The width of the bridges should be about equal to the thickness of the cylinder wall in order to make a good casting.

The Point of Cut-off. In our study of indicators we saw that if the point of cut-off is early, compression is early. Valve diagrams also show this fact to be true. If the cut-off is very early the compression is excessive. Except for locomotive and high speed engines where compression is an advantage the plain slide valve is not arranged to cut-off earlier than $\frac{1}{2}$ or $\frac{3}{4}$ the stroke. In case the early cut-off is desired large outside laps are necessary. In Fig. 20 we saw how cut-off was equalized by giving a greater outside lap at one end. This however caused inequality of lead.

Lead. The lead of stationary engines varies from zero to $\frac{3}{8}$ inch; $\frac{1}{16}$ inch being an average. The amount of lead is not proportioned by any rule; it is determined by experiment. Sometimes the engine is designed, built and set up before the lead is fixed.

For an engine having compression that produces pressure nearly or quite boiler pressure good results are obtained from little

or no lead. In case the ports are small and the clearance large, there should be considerable lead so that the piston will not move through a part of the stroke under a pressure less than the initial pressure. Valves that open slowly require more lead than quick-acting valves.

Let us design the slide valve and the valve seat.

The engine is $10'' \times 18''$, making 180 revolutions per minute.

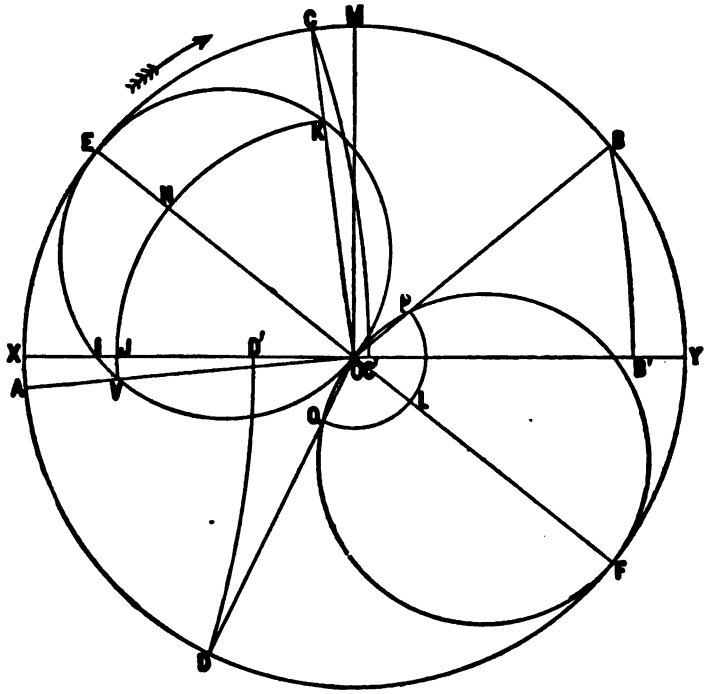


Fig. 25. Crank End.

By referring to page 30 we find the steam pipe should be 3 inches in diameter. We also find from page 30 that the width of the steam port should be about $\frac{7}{8}$ inch.

Before going further it will be necessary to design the valve.

Usually the valve travel is one of the variables to be determined but in this case we will assume it to be $3\frac{1}{2}$ inches and the connecting rod three times the length of the crank. Let us also assume the following for the crank end,

Outside lap	= $1\frac{1}{4}$ inches
Inside lap	= $\frac{3}{8}$ inch
Cut-off	= about $\frac{1}{2}$ stroke
Lead	= about .1 inch

For the head end,

Outside lap	= $1\frac{1}{8}$ inches
Inside lap	= $\frac{5}{8}$ inch

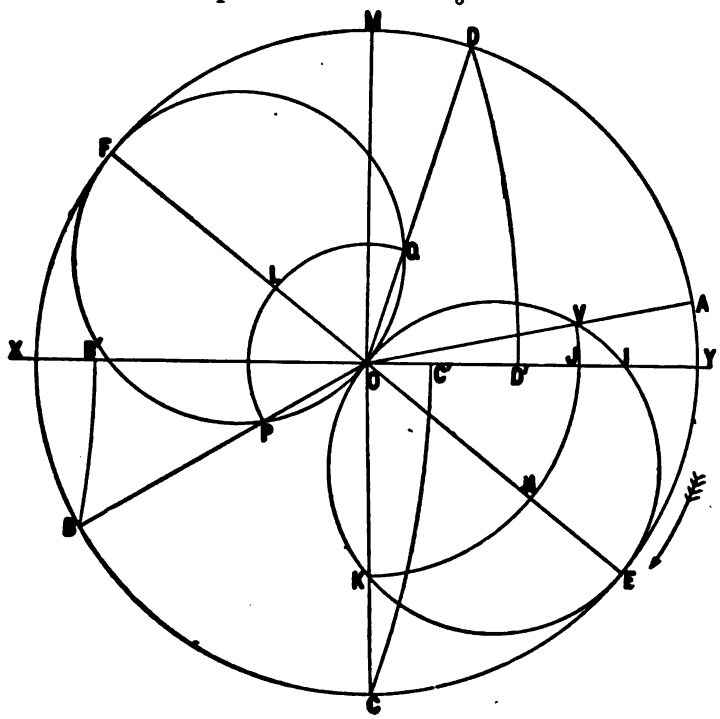


Fig. 26. Head End.

By making diagrams as shown in Figs. 25 and 26 we find

The angular advance	= 51° 30′
The angular lead	= 5° 30′
Cut-off, crank end	= .52 stroke
Cut-off, head end	= .40 stroke
Lead, crank end	= .1 inch
Lead, head end	= .25 inch
Compression, crank end	= .63 stroke
Compression, head end	= .71 stroke
Release, crank end	= .91 stroke
Release, head end	= .90 stroke

From the diagram we find the maximum port opening equals $\frac{1}{2}$ inch for the crank end and $\frac{5}{8}$ inch for the head end.

The above diagrams were drawn so that compression and release would be about equal and the cut-off nearly equal for both ends, without making the lead too great at the head end. Probably the angular advance would be changed a little to equalize the work done at either end after indicator cards had been taken.

We can now lay out the valve and seat. To lay out the valve begin at the crank end and make O C, Fig. 27, $= 1\frac{1}{4}$ inches which is the crank end outside lap. Then make C D equal to $\frac{7}{8}$ inch which is equal to the width of port.

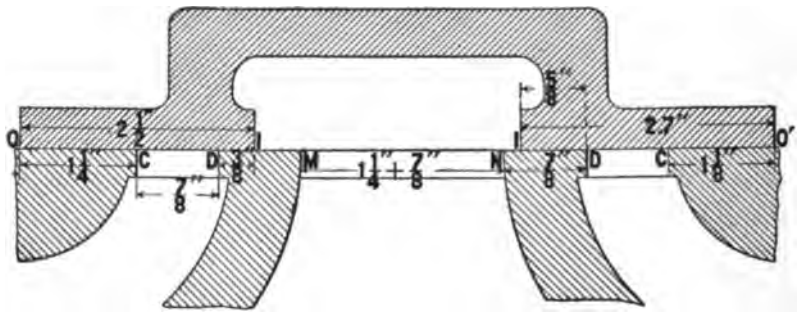


Fig. 27.

When the valve has moved a distance equal to its maximum displacement which is equal to $1\frac{3}{4}$ inches, it is in the position shown in Fig. 28. When in this position the point O must not overrun the edge M of the bridge. There should be enough width between O and M to make the valve steam tight. In Fig. 28 there is plenty of space, since the valve doesn't open the steam port wide. In case the valve moves too far the width D M must be increased. We will make the width of the bridge D M, $\frac{7}{8}$ inch.

The crank end inside lap is next laid out; D I $= \frac{3}{8}$ inch. This makes O I $= 1\frac{1}{4} + \frac{7}{8} + \frac{3}{8} = 2\frac{1}{2}$ inches. Again referring to Fig. 28 we see that I has moved, so that the exhaust port is nearly closed. According to the calculation for the exhaust port I N, Fig. 28, should not be less than C D; as it measures $\frac{7}{8}$ inch the conditions are satisfied. The exhaust port might be made wider but it couldn't be any narrower.

We can complete the valve, Fig. 27, by making N D $= \frac{7}{8}$

inch, D C = $\frac{7}{8}$ inch, C O′ = $1\frac{1}{8}$ inch, and is the outside lap of the head end. I D the inside lap of head end = $\frac{5}{8}$ inch.

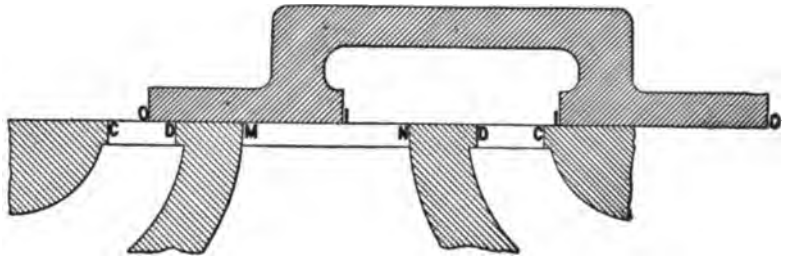


Fig. 28.

VALVE SETTING.

The principles of the valve diagrams are useful in setting valves as well as in designing them. The valve is usually set as accurately as possible when cold and after indicator cards have been taken, the final adjustment is necessary to correct slight irregularities.

The slide valve is designed with its parts fixed, that is, the laps cannot be altered without considerable labor. The radius of the eccentric, which determines the travel of the valve, is usually fixed. The adjustable parts are commonly the length of the valve spindle and the angular advance of the eccentric.

By lengthening or shortening the valve spindle the valve is made to travel an equal distance each side of the mid-position. Moving the eccentric on the shaft makes the action of the valve earlier or later as the angular advance is increased or decreased.

To Put the Engine on the Center. It is usual to put the engine on center before setting the valve. First put the engine in a position where the piston has nearly completed the outward stroke and make a mark on the guide opposite some part of the crosshead, the corner for instance. Also make a mark, with a center punch, on the frame of the engine near either the turned part of the pulley or crank disc. With this punch mark as a center describe an arc on the wheel rim, with a tram. A tram is a steel rod with its ends bent at right angles and sharpened.

Turn the engine past the center until the mark on the guide again corresponds with the chosen part of the crosshead, and

make another mark on the wheel with the tram, keeping the same center. With the center of the pulley or crank disc as a center, describe an arc on the rim, which intersects the two arcs drawn with the tram. Bisect the arc on the rim, included between the two short arcs and turn the engine until the new point is at a distance from the point on the frame equal to the length of the tram. The engine is now on the center. The engine can be set on the other center by the same method.

The engine should always be moved in the direction in which it is to run so that the lost motion of the wrist pin and crank pin will be taken up the right way. In case the engine has been moved too far, at any time, it should be turned back beyond the desired point and brought up to that point while the engine is moving the right way.

To Set the Valve With Equal Lead. Set the engine on the dead point and give the eccentric the proper angular advance. Adjust the length of the valve spindle to give the proper lead for that end. Now place the engine on the other dead point and measure the lead at that end. If the leads are unequal, correct half the error by changing the length of the valve spindle and the other half by altering the angular advance. In case the valve gear has a rocker, the length of the spindle should be such that the rocker will move as designed. The angular advance should not be changed; the equal lead should be obtained by means of the valve spindle or the eccentric-rod.

Second Method. In case it is difficult to turn an engine the following method may be used. First loosen the eccentric on the shaft and turn it around until it gives maximum port opening first at one end and then at the other. If the maximum port openings are not equal make them so by changing the length of the valve spindle by half the difference. When the above adjustment has been made, set the engine on dead center and give the valve the proper lead by turning the eccentric on the shaft. The angular advance is thus adjusted.

To Set the Valve for Equal Cut-off. Place the engine on the head end dead point, give the eccentric the proper angular advance and the valve the proper lead. Move the engine forward until cut-off occurs, then measure the displacement of the crosshead

from the beginning of the stroke. Continue moving the engine forward, until cut-off takes place on the return stroke; measure the displacement of the crosshead from the beginning of this stroke to this point.

In case the cut-off is earlier at the crank than at the head end the valve spindle is too short. Adjust the length of the spindle so that the inequality will be corrected. Now set the engine on the head-end dead point again and give the valve the proper lead by means of the eccentric. By repeating the process, making slight changes, the desired result will be obtained.

REVERSING GEAR.

In our consideration of the action of the slide valve, we have supposed that the engine always runs in the same direction and with a uniform ratio of expansion. By a uniform ratio of expansion we mean that cut-off always occurs at the same point. In some engines, locomotive and marine for example, the direction of working has to be changed frequently. Engines of these types must be provided with some mechanism that enables the engineer to reverse the engine without much trouble, as well as to alter the ratio of expansion. When a locomotive is starting a train, it must do more work than after the train is running. Therefore, at the start, the valve should have a late cut-off so that the mean effective pressure will be high. After the train is running, steam is cut-off early so the engine uses less steam per stroke and the steam used expands more. For this reason, there should be some means of altering the cut-off.

In Fig. 9, the right hand steam port is open to exhaust, the left hand port is open to live steam and the engine is going in the direction indicated by the arrow. Now suppose there is another eccentric keyed to the same shaft exactly opposite to the one now controlling the valve. If the valve were disconnected from the first and connected to the second the valve would be moved to the opposite end of its travel; the left hand port would now be open to exhaust and the right hand port would be open to live steam. The result would be, that the engine would commence to run in the opposite direction.

We know by referring to Fig. 8 that the eccentric radius

must be 90° + a in advance of the crank. If the crank is in the position O C, Fig. 29, and the eccentric radius in the position O Q, the engine will revolve in the direction indicated by the arrow D. To make the engine run in the opposite direction, it is only necessary to place the eccentric radius in the position O Q′; because the eccentric will then be in advance of the crank 90° + a.

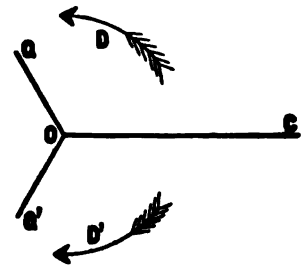


Fig. 29.

The Stephenson Link Motion. One of the earliest and one of the most common arrangements for reversing engines and changing the ratio of expansion, is the Stephenson link motion, illustrated in Fig. 30. The two eccentrics E and E′, whose centers are C and C′ respectively, are keyed to the crank shaft. The two eccentric rods R and R′ are connected to the slotted link L. The radius of curvature of the link is equal to the length of the eccentric rod. It is suspended from the point N by the system of levers. The block I fits the link, and slides in it when the link is raised or lowered. By moving the lever H, the link is raised by means of the bell-crank lever K and the rod M. The block I occupies positions from P′ to P, according to the position of the lever H.

The block I is connected directly to the spindle which drives the valve V.

When the block is in the position shown in Fig. 30 the eccentric rod R′ is nearly in line with the valve spindle, and the action of the valve is the same as if there were but one eccentric; the eccentric E will have little or no effect. In this position the block is nearest to P′ and is almost wholly under the influence of the eccentric E′.

Now, if the link is raised so that the block is near P, the steam distribution is controlled by the eccentric E since the eccen-

tric rod R is nearly in line with the valve spindle; the eccentric E′ will have practically no effect on the action of the valve. The engine will run in the opposite direction. The reason for this is understood by referring to Fig. 29.

When it occupies a position intermediate between P′ and P, the valve is under the influence of both eccentrics but most under the control of the nearest eccentric. In case it is in the exact center of the link it is controlled equally by both eccentrics; then the engine will not run in either direction.

Let us see what will happen when the block is intermediate between P′ and P but nearer P′ than P. The effect is important;

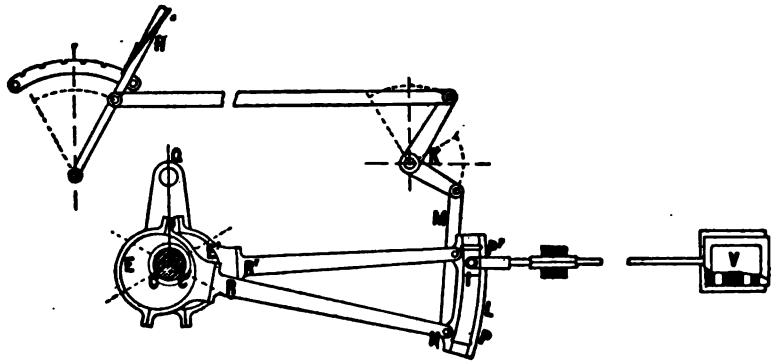


Fig. 30.

the block is influenced by both eccentrics, each working against each other. The block being controlled by the eccentric E′ causes the engine to run as in Fig. 30; the valve will not travel its full distance, or the eccentric diameter, but it will travel a distance which lessens as the block approaches the central point. Thus if the block is at P′ or P the valve will travel a distance equal to the diameter of the eccentric; if at any other point the travel is less.

The travel is the same as if the valve were driven by a new eccentric of less radius than either of those used.

The effect of decreasing the valve travel may be shown graphically by valve diagrams. It can be stated as follows; decreasing the valve travel causes cut-off to occur at a point earlier in the stroke; the ratio of expansion is therefore increased. Com-

pression is earlier and release occurs later; the lead also is reduced slightly.

Thus we see that the combination of a pair of eccentrics with a link and sliding block allows both the change in direction of the engine and a change in the ratio of expansion. For these reasons, this gear is employed in locomotive, marine, rolling-mill and winding engines.

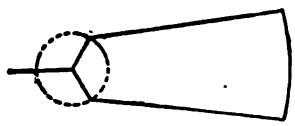


Fig. 31.

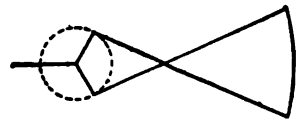


Fig. 32.

The link is curved so that the lead will be equalized for all travels.

The length of the link should not be less than three times the travel of the valve. It may be suspended from above or supported from beneath.

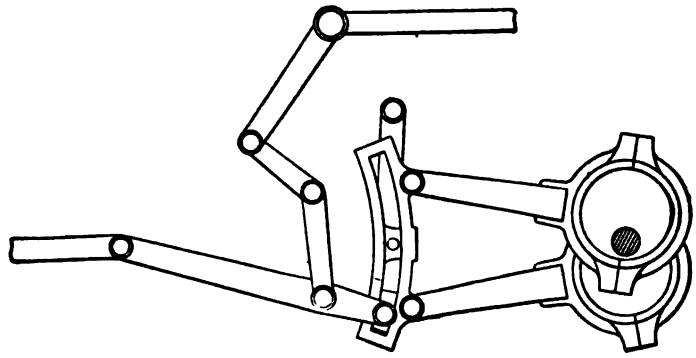


Fig. 33.

Open and Crossed Rods. The eccentric rods are called open or crossed according to their positions when the eccentrics are turned toward the link. If when the eccentrics are turned toward the link the rods are open as shown in Fig. 31 they are called open rods. If they are as shown in Fig. 32 they are crossed rods. The rods may be crossed when the eccentrics point away from the link and yet not be crossed rods.

With crossed rods the lead decreases from full to mid-gear while with open rods the lead increases. With crossed rods there

is no lead when in mid-gear. The engine may be stopped by placing the link in mid-gear if crossed rods are used.

Open rods are used more than crossed rods.

The Gooch Link. The action of this gear is equivalent to that of the Stephenson link. With this gear, shown in Fig. 33 the link is not raised or lowered but is **stationary**. The radius of curvature of the link is equal to the length of the radius rod which is moved so that the block occupies different positions in the link. If the link has a radius equal to the length of the radius rod, the block may be moved from one extremity of the link to the other without moving the valve. Therefore the lead must be constant for all points of cut-off.

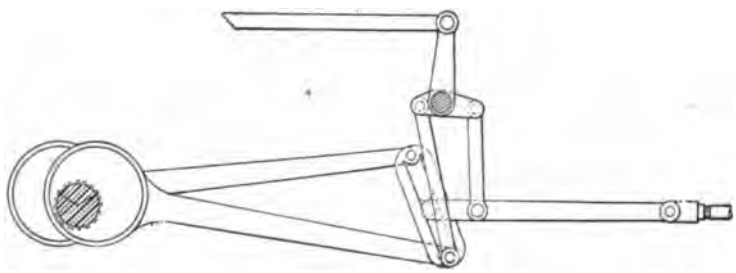


Fig. 34.

The Allen Link. At the time of the invention of the Stephenson gear the curved surfaces of the link could not be finished without considerable trouble and expense. In the Allen gear Fig. 34 the link is straight, for the change of gear is effected partly by shifting the link and partly by moving the block. This gear combines the most important features of both the Stephenson and the Gooch links; it is intermediate between them. It gives a variable lead; the variation is however less than that of the Stephenson gear. The Allen link is falling into disuse because the curved links can now be made without much trouble.

Comparison of the Stephenson and Gooch Links. The Gooch link gives constant lead; but it has more joints to wear and cause lost motion and it requires more space than the Stephenson. In choosing the type of link motion the importance of a given feature must be well considered. Both gears may be designed to give an equalized cut-off.

A locomotive is a slow speed engine when starting and a high speed engine when the train is under way. A slow speed engine requires but little lead, while for high speeds considerable lead, early admission, exhaust and a large amount of compression are necessary in order that the engine may run smoothly.

In starting a train, the link motion is thrown into full forward gear, which causes a late cut-off and slight lead. After the train is well started, the locomotive, like a high speed stationary engine, requires more lead and considerable compression. An early admission and release are desirable in order that the steam may be admitted and exhausted freely. By raising the Stephenson link, these conditions are attained as well as the advantage of using steam expansively.

In marine engines, the link motions are used more for revers-

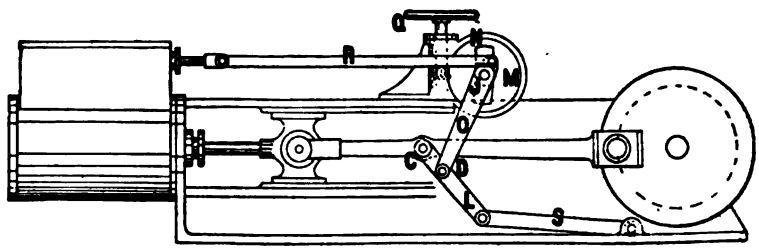


Fig. 35.

ing than for varying the expansion. Usually a marine engine runs at full speed and under full load. When the speed decreases, if the link is shifted toward mid-gear, there is excessive compression and early release. Engines of this type often use independent cut-off valves.

Joy Valve-gear. The complicated link motion, with its two eccentrics etc., is undesirable for expansion gear. One of the most common methods for driving valves without using eccentrics is the Joy valve gear. It can be used on all types of engines and is especially adapted for marine and locomotive work.

Fig. 35 illustrates this gear as applied to a horizontal engine. The rod L is attached at its upper end to the connecting-rod at the point C which is usually taken near the middle of the connecting-rod. The lower end of L is jointed to the radius rod S which causes L to move in a vertical plane. At some point

D on the link L, horizontal motion is communicated to the lower end of the arm O. From the upper end of the arm O motion is transmitted to the valve spindle through the valve rod R. The fulcrum J of the lever O is attached to a block which slides in the curved slot N. This slot has a radius of curvature equal to the length of the rod R and is cut in the disc M. The center J is carried vertically in the slot and partakes of the vertical movement of the connecting-rod; the extent of this vertical movement being equal to the vibration of the point C.

The center of the disc coincides with the center J of the lever O, when the lever is in the position corresponding to that of

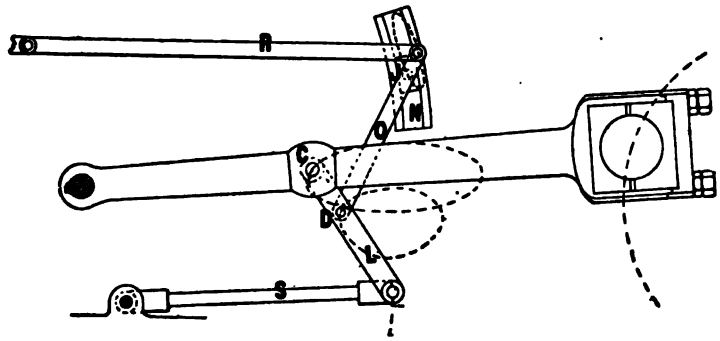


Fig. 36.

the piston at either end of its stroke. The disc can be rotated through an arc by means of the worm and wheel Q. Thus, the slot may be inclined to either side of the vertical, which controls the forward and backward motion and the rate of expansion. When the slot is exactly vertical the gear is in mid-gear.

If the lower end D of the lever O were attached directly to the connecting-rod, the motion of the point J about the center of the slot would not be symmetrical and the cut-off would not be equal for the two ends of the cylinder. By connecting D to the vibrating link L this defect is remedied. The point C describes an ellipse, while the point D describes a figure like an ellipse but slightly bulged as shown in Fig. 36. The amount of the bulge is regulated to correct the unequal motion of the fulcrum above and below the central position. This is accomplished by moving the point D.

This gear gives a rapid motion to the valve when opening and closing and less compression at short cut-off than the link motion.

The cut-off can be made nearly equal for all grades of the gear. It also gives constant lead. Some of its many joints are likely to wear loose and the numerous parts make it difficult to inspect the crank-pin and crosshead while the engine is running.

MODIFICATIONS OF THE SLIDE VALVE.

When very high pressure steam is used, there is a large amount of friction between the valve and its seat. With large valves, such for instance as those of locomotives or large marine engines, the amount of power necessary to drive the valve itself is considerable. The larger the engine the greater this defect.

The ordinary slide valve is suitable for small engines; but for large sizes some method must be employed to balance the great pressure on the back of the valve.

Piston Valve. The piston valve is common, especially in marine engines and is perfectly balanced, as far as steam pressure is concerned. Fig. 37 shows a section of the piston valve and the high pressure cylinder for one of the engines of the U. S. battleship "Massachusetts." The valve consists of two pistons connected by a sleeve through which the valve rod passes. This valve rod is prolonged to a small balancing piston. The upper end of the balancing cylinder is connected to the exhaust thus partially relieving the valve gear from the weight of the valve. This balancing piston is not at all necessary.

The valve seat is formed by two short cylinders or tubes of cast iron or brass which are accurately bored. The space surrounding the valve seats is in communication with the ports. The pistons are provided with spring packing rings to keep them steam tight. The passages through the seat are not continuous but are made up of numerous small openings; the bars of metal between the openings prevent the packing rings from springing out into the ports.

Steam may be admitted to the middle of the steam chest and exhausted from the ends or *vice versa*. With the former method, the live steam is well separated from the exhaust. Also the valve rod stuffing box is exposed to exhaust steam only. This is a good arrangement for the high pressure cylinder; if used for a cylinder in which there is a vacuum air may leak into the exhaust space

through the valve rod stuffing box. With this arrangement the steam laps must be inside and the exhaust laps on the outside.

A piston valve may be considered as formed by the revolution of the section of a plain slide valve about an axis and is designed as is the slide valve, *i. e.*, by valve diagrams. The action of a piston valve is the same as that of a slide valve. It has the great advantage of being balanced; the power necessary to drive it being

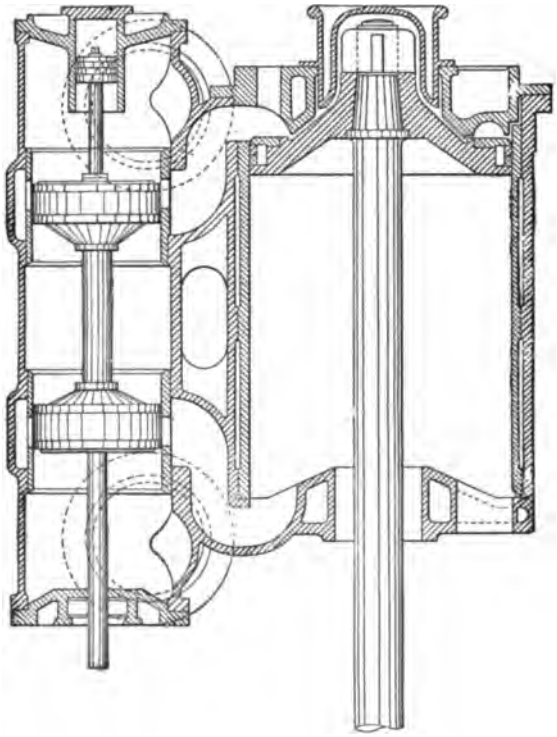


Fig. 37.

only that necessary to overcome the friction due to the spring rings. This valve and seat being circular in section are easily finished in the lathe.

A modified form of the piston-valve is used in the Valley automatic engines; the valve is square instead of circular.

Double-Ported Valve. Sometimes it is impossible to get sufficient port opening for engines of large diameter and short stroke, especially those having a plain slide valve with short travel. In

marine engineering a double ported valve shown in Fig. 38 is used. It consists of two slide valves each having its laps. The inner valve is similar to a plain slide valve except that there is communication between the exhaust space and the exhaust space of the outer valve which is long in order to supply steam to the inner valve. Each passage to the cylinder has two ports. A bridge separates the exhaust of the outer valve from the steam space of the inner valve.

The valve may be considered as equivalent to two equal slide valves of the same travel each having one half the total port opening. To admit the same amount of steam as a plain slide valve, the double-ported valve requires but half the valve travel; this is advantageous in high speed engines.

To balance the excessive steam pressure, the back of the valve

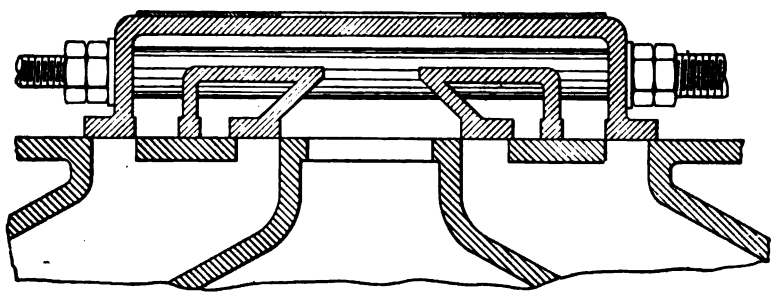


Fig. 38.

is sometimes provided with a projecting ring which is fitted to a similar ring within the top of the valve chest. These rings are planed true. Steam is then prevented from acting on the back of the valve. The space inside the rings is sometimes placed in communication with the condenser.

The Trick Valve. The defect of the plain slide valve, due to the slowness in opening and closing is largely remedied in the trick valve. This valve is so made that a double volume of steam enters during admission. Thus a quick and full opening of the port is obtained with a small valve travel. It may be used with link motion and other gears to give a variable cut-off.

In Fig. 39 the valve is shown in mid-position. It is similar to a plain slide valve except that there is a passage P P through it. It has an outside lap O and an inside lap I. The seat is raised

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and has steam ports S S, bridges B B and exhaust port E. If the valve moves to the right a distance equal to the outside lap plus the lead it will be in the position shown in Fig. 40. Steam will be admitted at the extreme left edge of the valve just the same as though it were a plain slide valve; also since steam surrounds the

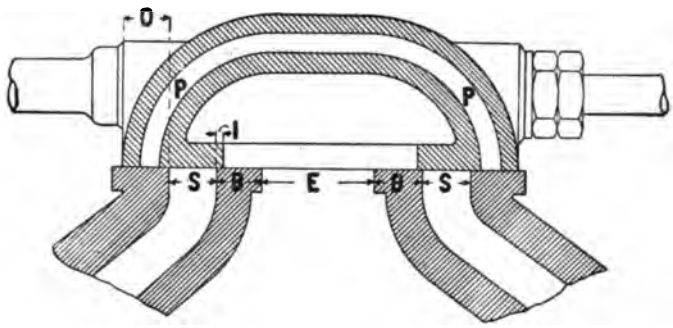


Fig. 39.

valve it will be admitted through the passage as shown in Fig. 40. If the lead is the same as for a plain slide valve, $\frac{1}{16}''$ for instance, this valve would give double the port opening when the valve was open a distance equal to the lead *i. e.*, $\frac{1}{8}''$.

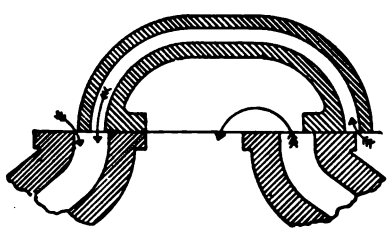


Fig. 40.

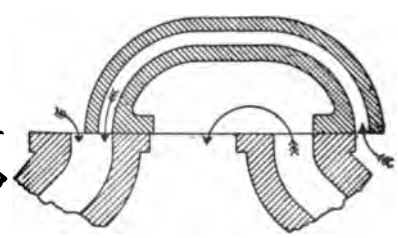


Fig. 41.

Fig. 41 shows the valve when it is in its extreme position to the right. The port is full open to steam.

Piston valves are also made with a passage similar to that of the Trick valve for double admission. The valve used with the Armington and Sims engine is perhaps the best example.

Balanced Valves. In most engines the difference between the pressures in the steam and exhaust pipes is considerable. Therefore the force holding the valve to its seat is great and consequently the friction is excessive. For this reason the valve gear

must be heavy and strong, and there is a considerable portion of the power developed by the engine consumed in driving the valves. Also the valve faces and seats soon become worn and leak.

There are numerous methods for relieving valves of a part of this pressure. Piston valves are commonly used on the high and intermediate cylinders of triple expansion engines. If well made and provided with spring rings there should be no leak. Small piston valves are often made without packing rings; but even if they fit the seat accurately when new, they soon become worn.

The double-ported valve, the trick valve and others often have some device for relieving the pressure. A bronze ring or cylinder is sometimes fastened to the back of the valve. This ring is pressed by springs against a finished surface of the valve chest cover. The space enclosed by the ring is often connected to the exhaust. The devices for balancing valves are usually costly and cause considerable loss from leakage.

DOUBLE VALVE GEARS.

Meyer Expansion Valve. We have seen how the plain slide valve regulates the distribution of steam. The valve diagrams show that if the valve is set to cut-off early, the other events will be early and the compression will therefore be excessive. A common method to reduce the disadvantages of the plain slide valve and the link motion is the adoption of a second valve which moves on the back of the ordinary valve and regulates the point of cut-off. There are several rider or cut-off valves but the Meyer valve is perhaps the simplest and most common. This valve is shown in section in Fig. 42. The main valve is shown at V; it has two passages P and P′ to enable the steam to reach the ports. The part between the passages being an ordinary D valve with its inside laps. On the back of the main valve, are the cut-off valves C and C′. They consist of two plates whose positions are adjusted by means of the right and left hand screw.

By referring to Fig. 42 it is seen that the right hand port is in communication with, while the cut-off valve has nothing to do with exhaust. The two valves are connected to separate eccentrics. The main or distribution valve is set to control admission, release and compression. Since a slight compression

is desired, the main valve is set for late cut-off; this will give late release and late compression, and also allow a wide range of cut-off. The cut-off valve may be controlled by a fixed eccentric or may be under the control of the governor. In some cases the gear is arranged so that the engineer can easily turn the cut-off valve spindle and so regulate the expansion.

With this gear lead, release and compression are entirely independent of the ratio of expansion. The cut-off is sharper because the cut-off valve is always moving in the opposite direction from the main valve, when closing the passages P or P′.

The proper proportions of the valves and the setting of the eccentrics may be determined by valve diagrams.

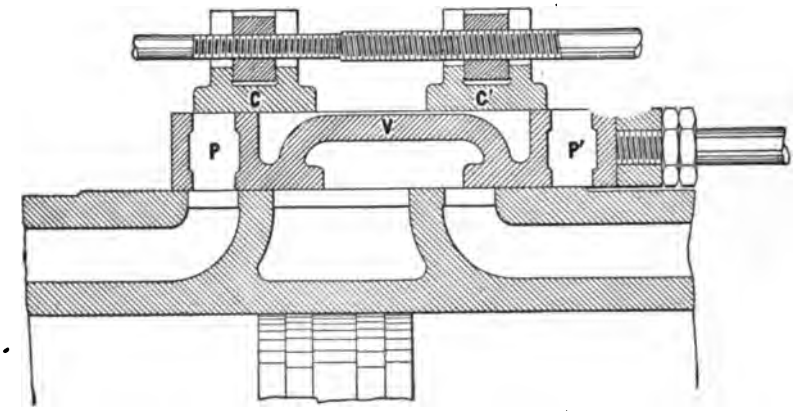


Fig. 42.

The Corliss Valve Gear. This gear is used on many engines especially those of the low speed stationary type. In the section on "Steam Engine" is shown an Allis Corliss engine. There are many varieties of the Corliss engines which differ in detail.

Figure 43 shows the side elevation of a Corliss cylinder. The sectional views are shown in Figs. 44 and 45. This gear has four separate and distinct cylindrical valves. There are two admission, or steam valves with their ports, one at each end of the cylinder, also an exhaust valve and port at each end. These valves have an oscillatory motion through a small arc, and are placed transversely across the cylinder extending nearly the entire width as shown in Fig. 45.

The valves are moved by means of an eccentric, wrist plate and valve stems.

The cranks O′ and Q′ are keyed to the exhaust valves R R (Fig. 43). The cranks are connected to the wrist plate by means

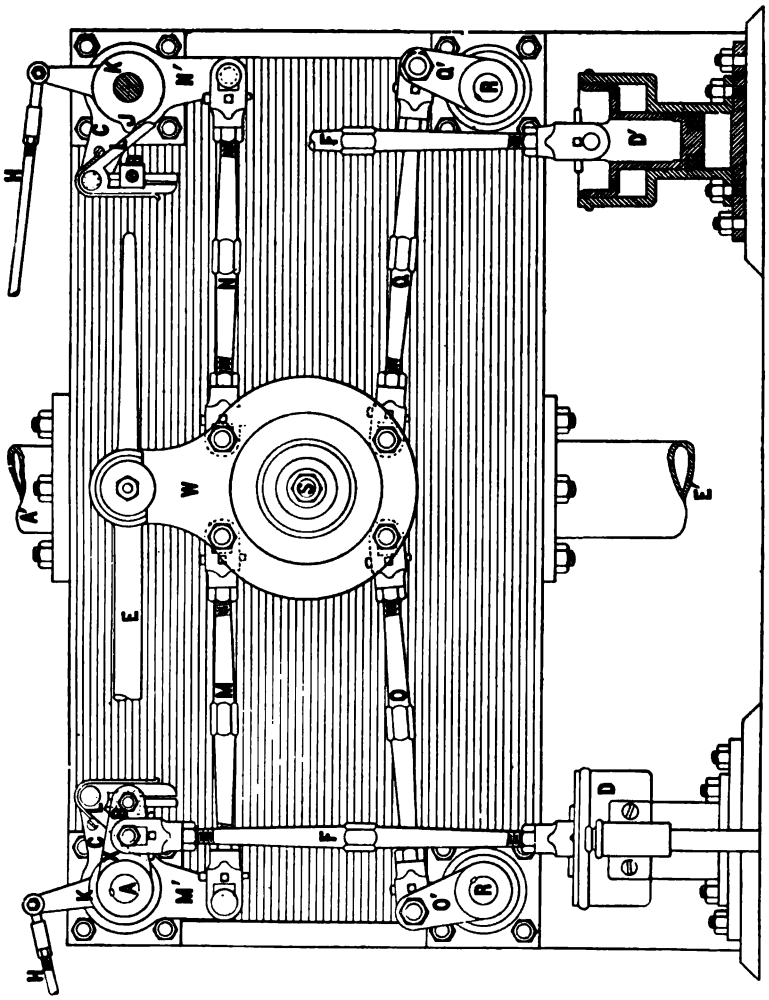
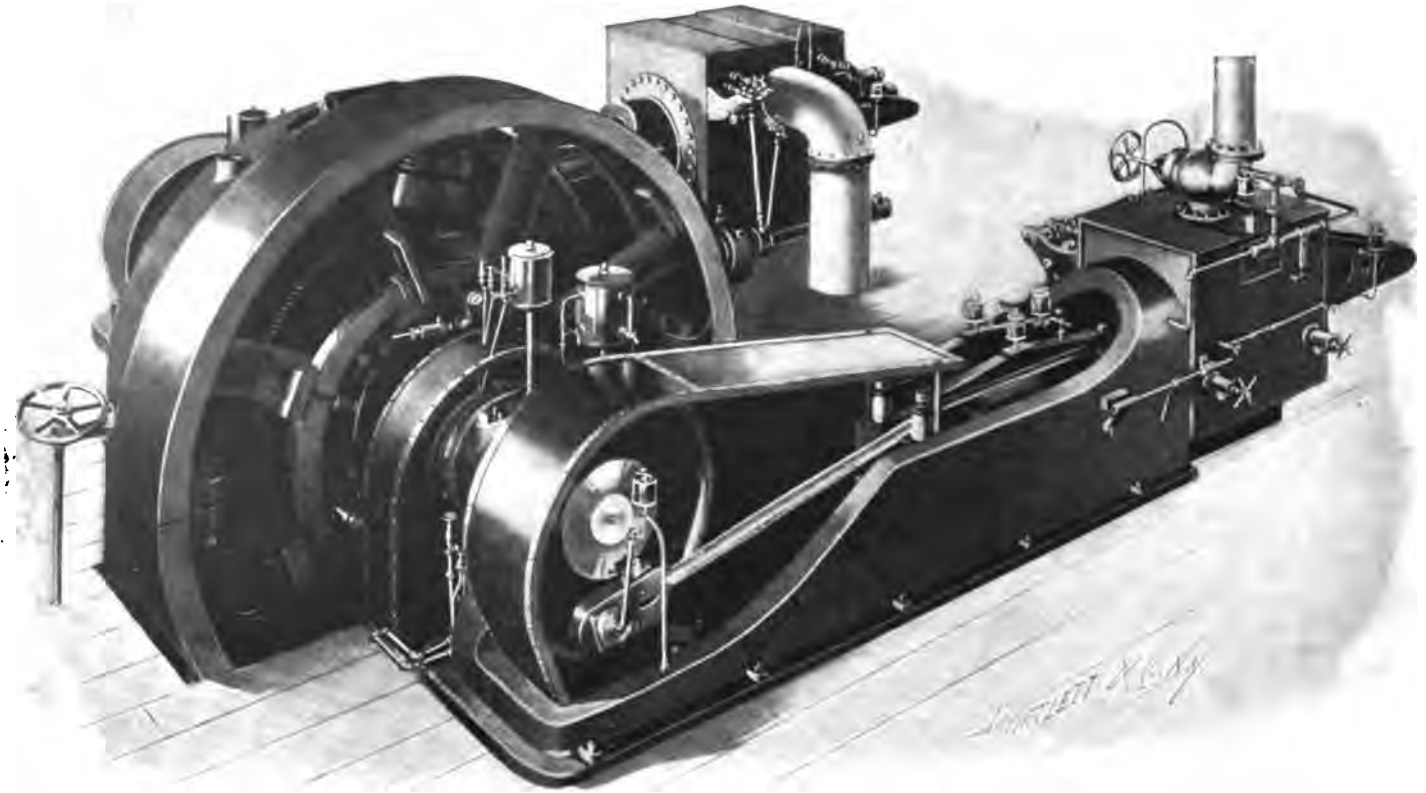


Fig. 43.

of the valve stems O and Q. The wrist plate W is made to rotate on the stud S by means of the eccentric rod E. As the wrist plate oscillates back and forth the exhaust valves which are connected to it, rotate with it. Rotating the valves opens and closes them.



850 HORSE-POWER HORIZONTAL CROSS-COMPOUND ENGINE, WITH DIRECT-DRIVEN ELECTRIC GENERATOR.
(Courtesy of McIntosh, Seymour & Company.)

The cranks M′ and N′ are keyed to the admission valves A and are connected to the wrist plate W by the valve stems M and N. The connections of the steam valves to the wrist plate are not permanent as are those of the exhaust valves but can be released. That is, the admission valves do not open and close as the wrist plate moves but are actuated by a releasing mechanism which is controlled by the governor.

The releasing mechanism is constructed in a great many ways. It is designed to hold the valve open for a given length of time and then, with the aid of a dash pot to close it quickly.

The cranks C C are provided with the disengaging links L L and are given a rotary motion by the wrist plate. The blocks B B

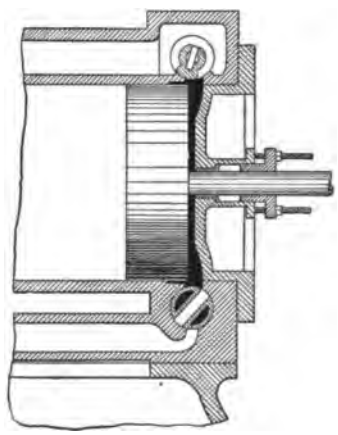


Fig. 44.

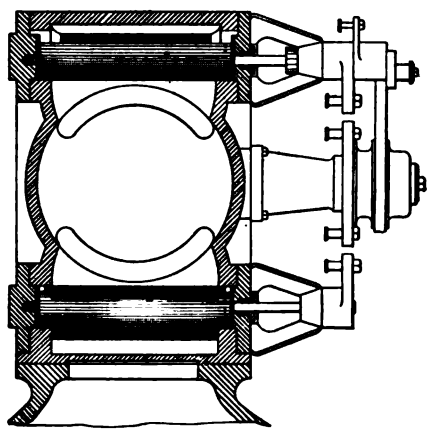


Fig. 45.

and the rods F F are connected to the cranks X which are keyed to the valves A. The bell cranks C C open the steam valves by hooking on the blocks B B. The projections J which are on the trip collars K K, unhook the disengaging links L L after the valves have been rotated by them through a certain angle. The cranks X are pulled back to their former positions by the dash pots D and D′, against whose resistance they were raised.

The links or valve stems M N O Q may be lengthened or shortened as desired. The valves are entirely separate from one another so that they may be made to open and close the ports at the right time. The valve stems are attached to the wrist plate

in such positions that the steam valves have their quickest movement at the time when the exhaust valves have their slowest movement. This arrangement together with the releasing gear causes the valves to open and close rapidly and maintain an ample port opening.

Steam enters at A′ and is exhausted at E′. The rods H H are connected to the governor.

The Corliss valve gear cannot be designed from diagrams like those of the plain slide valve. The dimensions of the various parts are determined by trial. The travel of the wrist plate should be sufficient to cause the valve to give full port opening, besides over travel of $\frac{1}{4}$ to $\frac{1}{2}$ inch to provide for short cut-off. The angle which the valve stems make with the crank is important. The greater the angle the more rapid the motion of the valve; but if the angle is made too great the crank will pass the center.

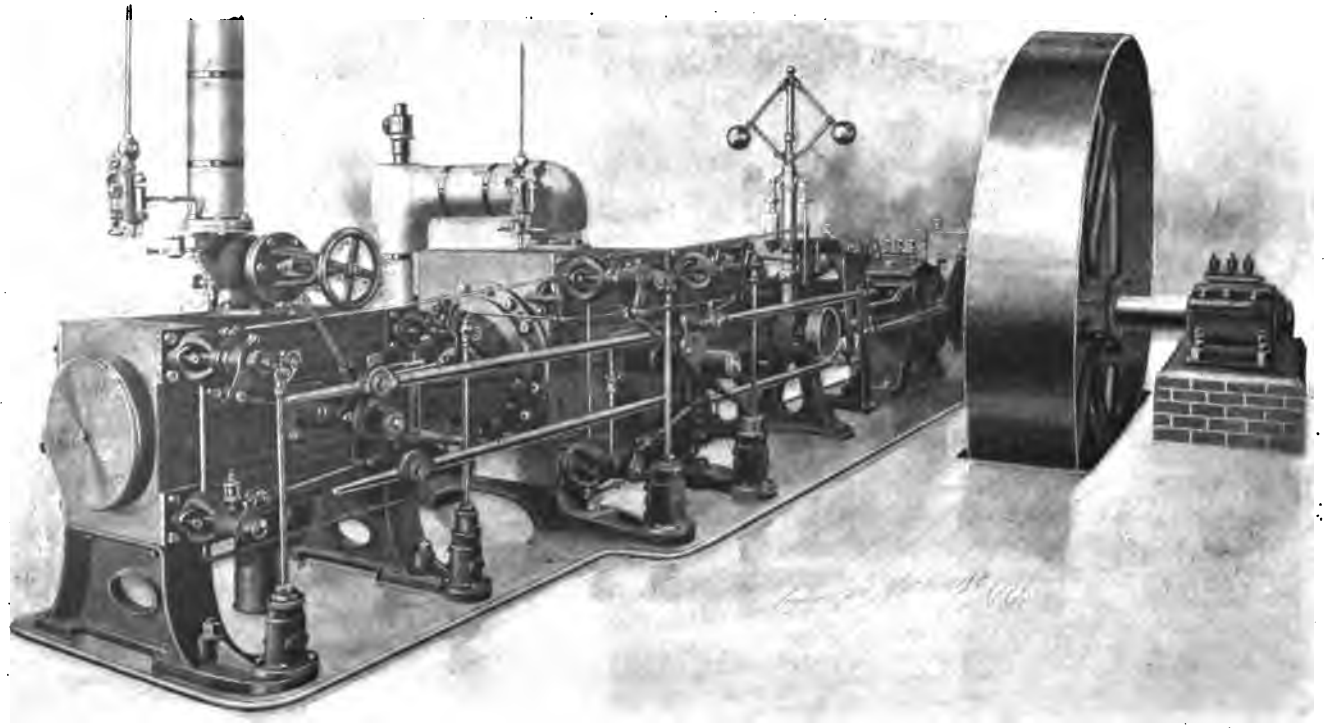
The Lap of the Valves. As the Corliss valves cannot be designed by means of valve diagrams, the amount of lap for the valves is not easily determined.

Cut-off occurs only when the wrist plate is moving in one particular direction. The valve must be closed before the motion of the wrist plate reverses or the cut-off will be near the end of the stroke. To have cut-off occur at about half stroke the eccentric must be set at right angles to the crank.

We saw in the study of the plain slide valve that the eccentric can be set at right angles to the crank only when the valve has no lap. The greater the lap the more the eccentric must be set ahead, or the greater the angular advance, in order that the valve can have the proper lead.

The steam valves are given lap, and the eccentric angular advance on account of the exhaust valves. In case the exhaust valves had no lap, release and compression would occur at the end of the stroke, instead of before the end as it should to obtain good distribution. Since the exhaust valves must have lap and there is but one eccentric the steam valves must have lap also. Therefore the eccentric must have considerable angular advance.

The advantages of the Corliss gear may be summed up as follows: quick acting valves diminish the loss from wire drawing; also the valves allow a wide range of cut-off; the clearance space



FISHKILL-CORLISS ENGINE, TANDEM COMPOUND

can be made small because of the short ports. The exhaust passages can be placed under the cylinder and detached from it, thus reducing the loss occasioned by having the exhaust steam in contact with the cylinder. The amount of power wasted in moving the valves is less than in the plain slide valve type of engine. Since the exhaust steam doesn't pass out by the admission ports, the waste by initial condensation is greatly reduced. The valves being independent of each other, the events of the stroke can be separately adjusted. We saw in the study of the plain slide valve that the events were dependent upon each other; as for instance, early cut-off causes excessive compression.

Engines having the Corliss gear cannot run at greater speed than about 125 revolutions per minute.

To Set the Corliss Valves. On the back bonnet side of the cylinder and on the back end of the valves there are radial lines which show the edges of the ports and valves. For each steam port there is a mark on the cylinder coinciding with the edge of the port which is toward the end of the cylinder; for each valve a mark on the back end of the valve coinciding with the edge of the valve toward the end of the cylinder. The lap movement of the steam valve is toward the end of the cylinder in which the valve is located. The opening edge of the exhaust port is the edge toward the center line of the cylinder and has its coinciding line upon the cylinder. On the exhaust valve is a mark which shows its opening edge. When the line on the back of the wrist plate hub coincides with the line on the hub boss, the wrist plate is in its central position.

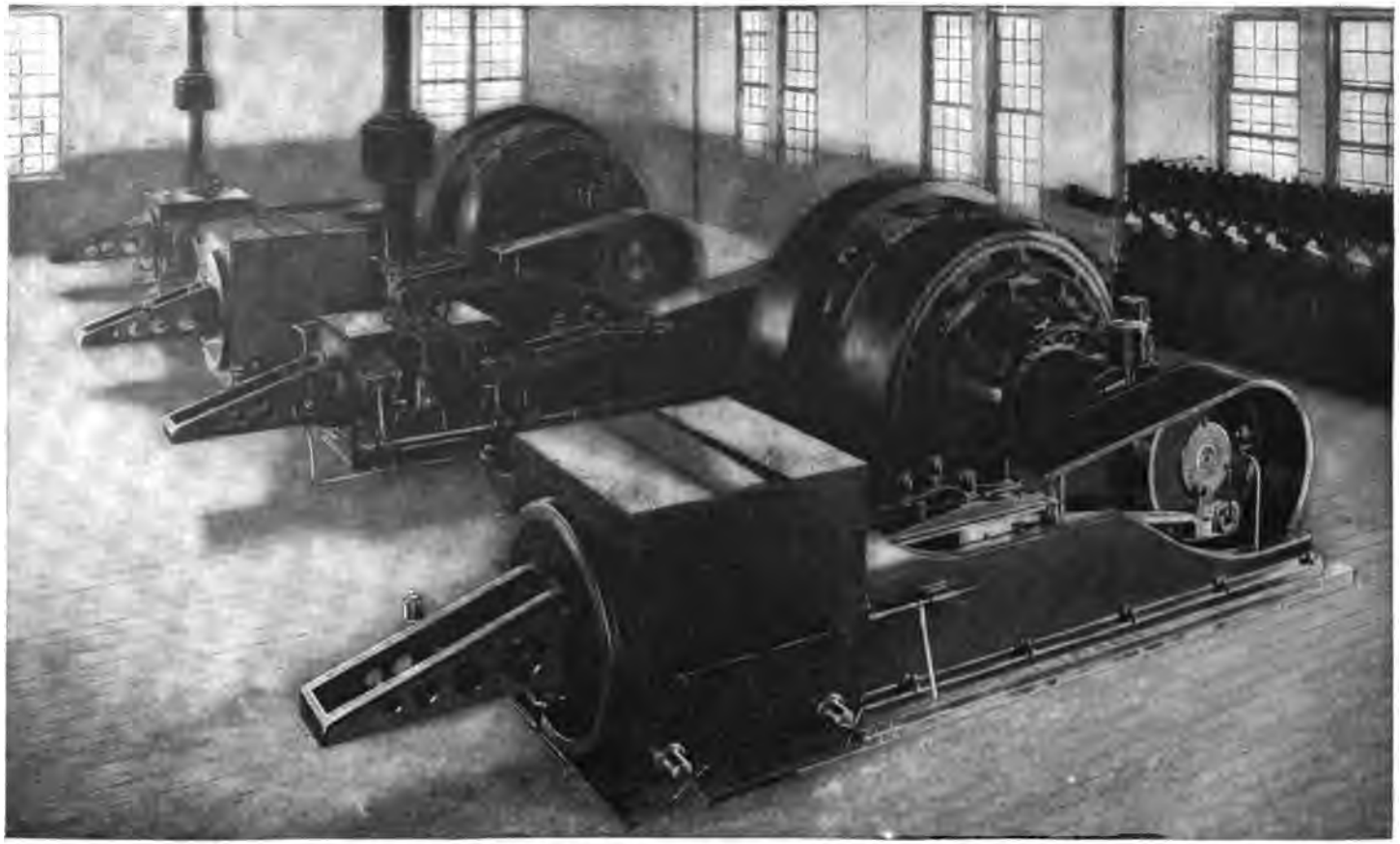
On either side of the center line, are lines which show the extremes of travel.

To set the valves, first hold the wrist plate on the center line. Then by means of the rods adjust the exhaust valves at the point of opening. The steam valves should be adjusted by the same means so that the laps will be from $\frac{1}{8}$ to $\frac{3}{8}$-inch depending upon the size of the engine. For an 8-inch cylinder, the amount should be about $\frac{1}{8}$-inch and for a 30-inch cylinder it should be $\frac{3}{8}$-inch. Intermediate sizes in proportion. The wrist plate should now be connected to the eccentric by the rod and hook. With the eccentric loose on the shaft, roll it over and see if the wrist plate

moves to the extremes of travel. Make it move to these extremes by adjustment of the eccentric rod at the screw and socket.

Now that the wrist plate is centered place the crank so that it is on forward dead center and roll the eccentric through an angle which is more than a quarter of a revolution in advance of the crank. This angle should be such that the lead will be from $\frac{1}{32}$ to $\frac{1}{8}$ of an inch according to the speed and size. Tighten the set screw in the eccentric and turn the engine over to crank dead center and see if the lead is the same as for the head end; if not adjust it by shortening or lengthening the valve rod.

To Adjust the Cut-off. Block the governor up to its usual running position and adjust the trip cams or releasing gear so that it will close the valve at the desired point of the stroke. The correctness of the cut-off adjustment may be tested by blocking up the governor, turning over the engine in the direction it is to run and making marks on the slides at the points where the crosshead is at cuts-off and ends of the stroke. If the cuts-off are equalized the distance traveled on the guides will be equal. If they are not equalized adjust by means of the cut-off rods to the governor. The pin in the side of the regulator column, upon which the balls rest should be removed when the engine is up to speed. This allows the stop motion cams to operate and stop the engine in case the governor belt breaks. Always turn the engine in the direction it is to run.



HORIZONTAL CROSS-COMPOUND ENGINES, BUILT BY McINTOSH, SEYMOUR & CO.,
550 Kw. Direct-Driven Power Generators. Speed, 130 Revolutions per Minute.

SECTION 6.

THE STEAM ENGINE.

PART II.

ACTION OF HEAT.

There are several types of heat engines, such as the steam engine, the gas engine, the hot-air engine, etc., each one of which derives its motive power from the heat contained in steam, gas, oil, hot air, or some other substance. Heat is imparted to these substances either by the combustion of fuel in a generator entirely separate from the engine, or by the combustion of a gaseous substance in the cylinder of the engine itself. In the case of the hot-air engine the heat is produced by a fire immediately beneath the engine.

Steam and hot gases have a tendency to expand, because of the heat they contain, thus producing a pressure in all directions. This pressure causes the piston of the engine to move, which allows the gas to expand. As the gas expands, it gives up heat, which is converted into useful work.

We shall now discuss the fundamental principles of the action of heat, and the behavior of gases and vapors, with special reference to the properties of steam and its action in the cylinder of the engine.

If a piece of iron or some other substance is placed in a fire, it becomes hotter than it was before, because heat from the fire has passed into it. If this hot substance is plunged into cold water, or is allowed to remain in a cool place, heat will pass from it, and we say that it becomes cold.

There have been many theories as to what heat is. The accepted theory of to-day is that heat is the result of motion, or we may say it is a form of kinetic energy. Heat is produced, not by the motion of the substance itself (for the hot body may be at rest), but by a rapid vibration of the minute individual particles that make up the body. These minute particles are called molecules. The faster the molecules vibrate, the greater will be their

kinetic energy and the hotter the substance will become. The hottest bodies are those that have the greatest energy of molecular vibration. A hot body can transfer its energy of vibration to another, which in turn becomes hotter than it was before, while the first body loses a part of its energy of vibration and becomes cooler. The terms hot and cold are only comparative terms; one body is hot because it contains a greater degree of heat than another; the other is cold because it contains a less degree of heat than the first. Cold, then, is simply a low degree of heat.

By temperature is meant simply the thermal condition of a body with reference to its capability of transferring heat to other bodies. If two bodies are placed in contact and the first gives more heat to the second than it receives, we say that No. 1 is hotter than No. 2. If the first receives more heat than it gives, No. 2 is hotter than No. 1. If both bodies give and receive the same amount of heat, they are of the same temperature.

According to our theory, it is evident that temperature depends upon the energy of molecular vibration. If the temperature rises, it means that the molecular vibration, and consequently the energy, increases; if the temperature falls, the energy of molecular vibration decreases. Evidently a point must finally be reached when this energy of vibration is zero and the molecules are at rest. At this temperature there is no heat and we call it the absolute zero. It is evident that this zero is very much below the zero of the ordinary scale.

In order to determine just how hot a body is, we must compare its temperature with that of some substance whose degree of heat we know. It would be impossible to keep several bodies at different degrees of heat for comparison, so we must resort to some other means. A simple method is to use some substance whose volume changes a definite amount for a definite change in temperature and always has the same volume for the same temperature. Mercury and alcohol are suitable substances and may be placed in a glass bulb, to which is connected a glass tube of small bore. All the air is drawn out of the tube, and the end is sealed so that the thermometric substance can expand or contract in a vacuum. The tube having been sealed, the bulb is placed in melting ice and the height of the mercury in the tube noted. It is then placed

in steam (or boiling water) at atmospheric pressure and the height of the column again noted. On the Fahrenheit scale the melting point is called 32°, and the boiling point 212°, and the intervening space is divided into 180 equal parts. In the Centigrade scale the melting point is called 0 and the boiling point 100°; there are 100 equal intervals between them. Thus we see that 180° F = 100° C, or 1° C = 1.8° F.

Example: What is the temperature of 50° C on the F scale?

$$50° \text{ C} = 50 \times 1.8 = 90° \text{ F above the melting point}$$

$$\text{or } 90 + 32 = 122° \text{ F above zero.}$$

In order to compare temperatures, we place the thermometer in contact with the substance whose degree of heat we wish to know and then observe the height of the liquid column in the thermometer. The height of this column depends upon the expansion of the thermometric substance and indicates the intensity of heat, or the temperature as we commonly call it. We use a thermometer to measure the *intensity* of heat, but not the *quantity* of heat.

For measuring the intensity of heat, the degree is the unit; for measuring the quantity of heat we have another unit, which is the amount of heat necessary to raise one pound of water from 61° F to 62° F. This is called the British thermal unit (B. T. U.). To raise one pound of water from 60° F to 62° F, or to raise two pounds from 60° F to 61° F, will require 2 B. T. U.

Suppose we have a small bar of iron heated to a white heat; its temperature will be high, but it will contain a relatively small quantity of heat, that is, it will not require a great many B. T. U. to raise its temperature to this high point. But suppose this same number of heat units were transferred to a ton of iron; the temperature would scarcely be changed, for the infinitely greater number of particles would have a correspondingly less number of vibrations.

Experience teaches us that when a rifle-ball strikes a target it stops, and that the energy which it possesses by virtue of its bodily motion is suddenly transformed into energy of molecular motion. Energy is indestructible; the molecular motion of the impinging body is at once increased and heat is developed. In general, whenever moving bodies are brought to rest, either sud-

denly as by impact or gradually as by friction, the kinetic energy of the moving mass is transformed into molecular kinetic energy, and we say that the bodies become heated.

We have now seen that we can transform energy of motion into heat. Also by means of suitable apparatus we can transform heat into energy of motion. Heat is the lowest form of energy, and while it is comparatively easy to transform other forms into heat, it is not as easy to change heat into the higher forms of energy. The principle of the transformation is simple enough, but if we are to have an efficient engine, we must be able to extract practically all of the heat from the working substance. This, however, is impossible, because the ordinary ranges of temperature used in practice are so far removed from the absolute zero of temperature, that with the most perfect machines we can at best recover but a fraction of the heat; the rest passing out of the engine.

The transformation is accomplished by means of a working substance which passes from the temperature of a heat generator into a refrigerator; the heat given up during the change is transformed into work. By the term refrigerator we mean the low temperature of the working substance at exhaust. The greater the temperature of the source of heat, or the lower the temperature of the refrigerator, the greater will be the amount of heat that can be abstracted and converted into useful work. If the temperature of the refrigerator could be reduced to the absolute zero, all the heat would be removed from the working substance, and the only loss would be that due to mechanical imperfections of the engine; but since the absolute zero is 461° below the zero on the Fahrenheit scale, or 493° below the freezing point, we must at best allow a relatively large amount of heat to pass out of the engine into the refrigerator without having done any work at all.

The unit of work is the foot-pound; that is, the work done in raising one pound one foot. By means of careful experiments it has been determined that for every 778 foot-pounds of work transformed into heat there is developed one B. T. U. This value 778 is known as the Mechanical Equivalent of heat. It means that one B. T. U. and 778 foot-pounds of work are mutually interchangeable.

EXPANSION OF GASES.

A perfect gas, strictly speaking, is one that cannot be liquefied; ordinarily, however, we apply the term to those gases that can be liquefied only with great difficulty, that is, under extreme pressure and a great reduction of temperature. For every perfect gas there is a definite relation between the pressure and volume, and what is known as Boyle's Law has been found to hold true, *viz.:* The pressure of a perfect gas at constant temperature varies inversely as the volume; that is, if the temperature remains constant the pressure becomes less as fast as the volume becomes greater, or conversely the volume becomes less as fast as the pressure becomes greater. Now if the pressure becomes twice as great, the volume becomes half as large, and if the volume becomes three times as great, the pressure will be only one-third as much. Hence we see that however the pressure may vary, the volume will change in such a way that the pressure multiplied by the volume will always be constant, provided the temperature remains the same.

This simple law is expressed thus:

$$P \times V = C$$

In which

P = pressure in pounds per square inch (absolute)

V = volume in cubic feet

C = a constant which has different values for different gases.

Gases that are not easily liquefied, such as hydrogen, oxygen and air, follow this law fairly well, but those that are easily liquefied, such as steam and ammonia, do not follow it at all.

The value of C is not the same for all gases, and as no gas is, strictly speaking, a perfect gas, its value varies slightly with the temperature. For air, which is nearly a perfect gas, its value is 182.08 at 32° F.

Example.—What is the absolute pressure per square inch of one pound of air if the temperature is 32° F, and the volume 4.129 cubic feet?

$$V = 4.129$$

$$P \times V = C \quad \text{or} \quad P = \frac{C}{V} = \frac{182.08}{4.129}$$

P = 44.1 pounds per square inch, absolute.

Let us discuss this law by means of a diagram. Fig. 1 is drawn with O Y and O X at right angles to each other; pressures are measured to any convenient scale on O Y and volumes on O X. O C represents 12.387 cubic feet and O D represents 14.7 pounds, since $P \times V = 182.08$. O F represents 24.774 cubic feet and O G 7.35 pounds. In like manner O L represents 6.19 cubic feet and O N 29.41 pounds. Then if we draw perpendiculars to O X at L, C and F, and perpendiculars to O Y at N, D and G, they will meet in the points M, E and H. The curve A B is drawn through these points. Then for any pressure we can find the corresponding volume or *vice versa*. The area of the rectangle O D E C equals that of the rectangle O G H F and also that of the rectangle O N M L. That this is so is readily seen from the fact that the product of the pressure and its corresponding volume is constant.

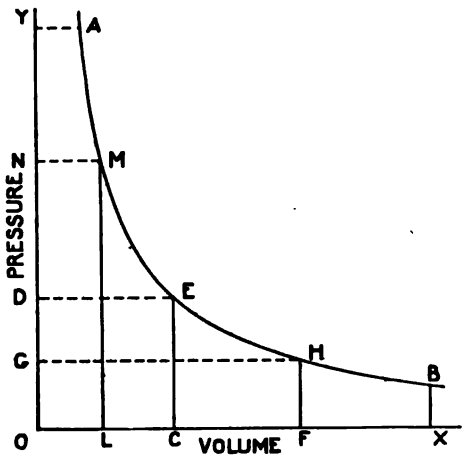


Fig. 1.

If we plot a curve using this equation we will get a rectangular hyperbola, as shown in "Steam Engine Indicators." This curve is called an isothermal curve or curve of equal temperatures.

If the volume of a perfect gas remains constant, the pressure will vary as the temperature. Or, if the pressure remains constant, the volume will vary as the temperature. This is known as the Law of Charles. From this we see that, as the temperature decreases, either the pressure or the volume will decrease a proportionate amount, and this must continue as long as there is any heat in the gas; finally a low temperature (the absolute zero) will be reached, where there is no more heat, and consequently either the pressure or the volume must be zero, provided this law holds true at such a very low temperature.

The law states that any change of pressure or volume is pro-

portional to the change in temperature, that is, the new volume is equal to the first volume plus or minus some fractional part of this volume, called the coefficient of expansion, multiplied by the change in temperature. We may express the formula thus:

$$P_1 V_1 = P V + (P V) k \times t$$
$$= P V (1 + k t).$$

Where P_1 and V_1 are the new pressure and volume
P and V are the first pressure and volume
k is the coefficient of expansion for the gas
t is the change in temperature.

From Boyle's Law we know that $P V = C$; hence we may write the above equation:

$$P_1 V_1 = C (1 + k t)$$
$$= C (\frac{1}{k} + t)$$

From careful experiments on the expansion of air, Regnault determined the value of the coefficient k to be .003654 for Centigrade units. This value is constant between freezing point, 0, and boiling point, 100°. Substituting this value of k in our last equation, we have:

$$P_1 V_1 = C (\frac{1}{.003654} + t)$$
$$= C (273.7 + t).$$

Now if we should make the change of temperature, t, equal to $-273.7°$ we should have:

$$P_1 V_1 = C(273.7 - 273.7) = 0$$
$$P_1 V_1 = 0.$$

Therefore we must have reached the absolute zero at $-273.7°$ below the freezing point, because here $P_1 \times V_1$ has reached 0, as we have previously seen must be the case at the absolute zero. $273.7 \times 1.8 = 492.7°$ for the F scale. Therefore the absolute zero is $492.7° - 32° = 460.7°$ below zero on the Fahrenheit scale. For ordinary work 461 will be sufficiently accurate.

If we let P = absolute pressure in pounds per square inch
V = volume of one pound in cubic feet
T = absolute temperature on Fahrenheit scale,

Then, $$P V = C T.$$

C equals .3693 for air.

Example.—If one pound of air occupies 16.606 cubic feet at a pressure of 14.7 pounds per square inch, what is its temperature?

$$P \times V = C \times T$$
$$14.7 \times 16.606 = .3693 \times T$$
$$T = \frac{244.108}{.3693}$$
$$T = 661.$$

This value 661 is absolute temperature, and to find the Fahrenheit temperature 461 must be subtracted from it. Thus, $661° - 461° = 200°$ F.

Saturated Vapor. The process of converting a liquid into a vapor is known as vaporization; the product thus formed is readily condensed and therefore does not follow the laws of perfect gases at all. A dry saturated vapor is one that has just enough heat in it to keep it in the form of a vapor; if we add more heat it becomes superheated. A superheated vapor may lose a part of its heat without condensation; a saturated vapor cannot. When a saturated vapor loses a part of its heat some of it will condense and we say that the vapor is wet.

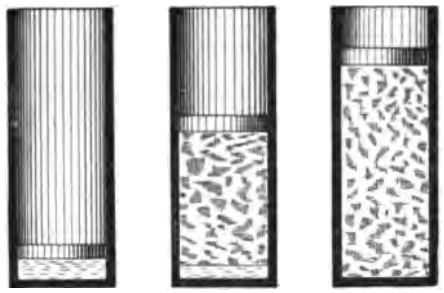


Fig. 2.

Steam is simply the vapor from water and we shall confine our discussion to this alone. Suppose we have a vertical cylinder, as shown in Fig. 2, fitted with a light piston free to move up and down, yet so constructed that it may be loaded at will. Suppose that there is one pound of water at a temperature of 32° F in the bottom of this cylinder, and that the piston rests upon its surface. Now, if we apply heat by means of a gas flame or fire, we shall notice the following effects:

First.—The temperature of the water will gradually rise until it reaches the temperature at which steam is formed. This temperature will depend upon the pressure, or the load on the

piston. If the piston is very light, we may neglect its weight and consider that there is simply the atmospheric pressure of 14.7 pounds per square inch acting on the water surface. At this pressure steam will begin to form at 212° F.

Second.— As soon as 212° F is reached, steam will begin to form and the piston will steadily rise, but no matter how hot the fire may be, the temperature of both water and steam will remain at 212° until all the water is evaporated. We had one pound of water at 32° F and at 14.7 pounds absolute pressure, and found that steam formed at a temperature of 212° F and remained at that temperature. We added 180.9 B. T. U., the heat of the liquid, to bring the water from 32° to the boiling point. To convert water at 212° into steam at 212°, we added 965.7 B. T. U. more. This quantity, known as the latent heat, or heat of vaporization, makes the total heat 1,146.6 B. T. U. If we should measure the volume carefully after all the water was evaporated, we should find that there was just 26.36 cubic feet of dry saturated steam. We had one pound of water, and therefore must have one pound of steam, for none of it could escape; hence one cubic foot will weigh $\frac{1}{26.36} = 0.03794$ pounds, which is known as the density of steam at 14.7 pounds absolute pressure or 212° F. In the Table of Properties of Saturated Steam (see page 14) all these quantities are found in the order given and at the pressure of 14.7 pounds above vacuum.

Suppose now we place a weight of 85.3 pounds on the piston. The pressure is 85.3 pounds plus 14 7 pounds, or 100 pounds absolute. We shall now find that no steam will form until a temperature of 327.58° is reached. Starting with water at 32°, it will be necessary to add 297.9 B. T. U. before a temperature of 327.58° is reached, and also we must add 884.0 B. T. U. more to vaporize it, making a total heat of 1,181.9 B. T. U. Under this greater pressure the steam occupies a volume of only 4.403 cubic feet, or one cubic foot of it weighs $\frac{1}{4.403} = 0.2271$ pound.

Of course it would be impossible to determine all these different quantities by actual experiment, and at all pressures varying from vacuum to the high pressures, used in water-tube boilers.

Fortunately we are able to compute them all from equations which have been carefully determined by experiment. If saturated steam were a perfect gas, we could easily calculate all the relations of pressure, volume and temperature from the equation $PV = CT$, but steam is so far removed from the state of a perfect gas that these relations do not hold, and the true equations become very complex. The following equation proposed by Rankin is one of the simplest, and gives fairly good results:

$$\log_{10} P = A - \frac{B}{T} - \frac{C}{T^2}$$

in which P = pressure in pounds per square inch above vacuum.

A = 6.1007

B = 2,732

C = 396,945

T = absolute temperature in Fahrenheit degrees.

By the aid of such equations as this, all the different quantities found in the steam tables may be calculated. These equations are based on careful experiments and give very satisfactory results.

Steam Tables. We have already seen that any change in the temperature of saturated steam produces a change of pressure, and that every change of pressure corresponds to a certain change in temperature. There are several properties of saturated steam that depend upon the temperature and pressure; and the values of all these different properties when arranged for all temperatures and pressures are called Steam Tables. The following are the principal items that are found in the tables:

1. The absolute pressure in pounds per square inch; it is equal to the gage pressure plus the atmospheric pressure of 14.7 pounds.

2. The temperature of the steam, or boiling water, at the corresponding pressure.

3. The heat of the liquid; or the number of B. T. U. necessary to raise one pound of water from 32° F to the boiling point corresponding to the given pressure.

4. The heat of vaporization, or the latent heat; this is the number of B. T. U. necessary to change one pound of water, at the boiling point, into dry saturated steam at the same temperature and pressure.

BALL ENGINE.

5. The total heat; or the number of B. T. U. necessary to change one pound of water from 32° F into steam at the given temperature or pressure. The total heat is evidently equal to the sum of the heat of the liquid and the heat of vaporization.

6. The density of the steam; that is, the weight in pounds of one cubic foot of steam at the given temperature or pressure.

7. The specific volume; or volume in cubic feet of one pound of steam at the required temperature or pressure. Evidently the specific volume is equal to $\frac{1}{\text{density}}$.

All these properties have been calculated by means of various formulas which have been deduced from the results of actual experiment. There are several formulas for the temperatures and pressures of steam; as some computers have used one and some another, there is likely to be a slight discrepancy between the tables computed by different authors. Rankin's formula, already given, is the simplest, but is not generally considered to be quite as accurate as some of the later ones; it has probably been used, however, more than any other.

The total heat may be calculated by means of the formula

$$H = 1{,}091.7 + 0.305\ (t - 32) \qquad [1]$$

in which H = total heat

t = temperature in degrees Fahrenheit.

The heat of the liquid is equal to q.

$$q = t + 0.00002\,t^2 + 0.0000003\,t^3 \qquad [2]$$

in which t = temperature in degrees Centigrade.

These constants are for use in the Centigrade system only. To calculate the heat of the liquid for any Fahrenheit temperature it is necessary to change the Fahrenheit into equivalent Centigrade degrees and then substitute in the above formula.

The formula used for the calculation of specific volume is too complex for consideration here, but the relation of pressure and volume may be approximately expressed by means of an equation of the form $P\,V^n = C$, in which n is an exponent, C a constant, P the absolute pressure, and V the specific volume; n is usually taken to be $\frac{17}{16}$, and C to be 475.

On pages 14 and 15 are given tables of the properties of

TABLE OF PROPERTIES OF SATURATED STEAM.

Pressure in pounds per sq.in. above vacuum.	Temperature in degrees Fahrenheit.	Heat in liquid from 32° in units.	Heat of vaporization, or latent heat in heat units.	Total heat in heat units from water at 32°.	Density or weight of cubic ft. in pounds.	Volume of 1 pound in cubic feet.	Total pressure above vacuum.
1	101.99	70.0	1043.0	1113.1	0.00299	334.5	1
2	126.27	94.4	1026.1	1120.5	0 00576	173.6	2
3	141.62	109.8	1015.3	1125.1	0.00844	118.5	3
4	153.09	121.4	1007.2	1128.6	0.01107	90.31	4
5	162.34	130.7	1000.8	1131.5	0 01366	73.21	5
6	170.14	138.6	995.2	1133.8	0.01622	61.67	6
7	176.90	145.4	990.5	1135.9	0.01874	53.37	7
8	182.92	151.5	986.2	1137.7	0.02125	47.06	8
9	188.33	156.9	982.5	1139.4	0.02374	42 12	9
10	193.25	161.9	979.0	1140.9	0.02621	38.15	10
14.7	212.00	180.9	965.7	1146.6	0.03794	26.36	14.7
15	213.03	181.8	965.1	1146.9	0.03826	26.14	15
20	227.95	196.9	954.6	1151.5	0.05023	19.91	20
25	240.04	209.1	946.0	1155.1	0.06199	16.13	25
30	250.27	219.4	938.9	1158.3	0.07360	13.59	30
35	259.19	228.4	932.6	1161.0	0.08508	11.75	35
40	267.13	236.4	927.0	1163.4	0 09644	10.37	40
45	274.29	243.6	922.0	1165.6	0.1077	9 287	45
50	280.85	250.2	917.4	1167.6	0.1188	8.414	50
55	286.89	256.3	913.1	1169.4	0.1299	7.696	55
60	292.51	261.9	909.3	1171.2	0.1409	7.097	60
65	297.77	267.2	905.5	1172.7	0.1519	6 583	65
70	302.71	272.2	902.1	1174.3	0.1628	6.143	70
75	307.38	276.9	898.8	1175.7	0.1736	5.762	75
80	311.80	281.4	895.6	1177.0	0.1843	5.426	80
85	316.02	285.8	892.5	1178.3	0.1951	5.126	85
90	320.04	290.0	889.6	1179.6	0.2058	4.859	90
95	323.89	294.0	886.7	1180.7	0.2165	4.619	95
100	327.58	297.9	884.0	1181.9	0.2271	4.403	100
105	331.13	301.6	881.3	1182.9	0.2378	4.205	105
110	334.56	305.2	878.8	1184.0	0.2484	4.026	110
115	337.86	308.7	876.3	1185.0	0.2589	3.862	115
120	341.05	312.0	874.0	1186.0	0.2695	3 711	120
125	344.13	315.2	871.7	1186.9	0.2800	3.571	125
130	347.12	318.4	869.4	1187.8	0.2904	3.444	130
140	352.85	324.4	865.1	1189.5	0.3113	3.212	140
150	358.26	330.0	861.2	1191 2	0.3321	3.011	150
160	363.40	335.4	857.4	1192.8	0.3530	2.833	160
170	368.29	340.5	853.8	1194.3	0.3737	2.676	170
180	372.97	345.4	850.3	1195.7	0.3945	2.535	180
190	377.44	350.1	847.0	1197.1	0.4153	2.408	190
200	381.73	354.6	843.8	1198.4	0.4359	2.294	200
225	391.79	365.1	836.3	1201.4	0.4876	2.051	225
250	400.99	374.7	829.5	1204.2	0.5393	1.854	250
275	409.50	383.6	823.2	1206.8	0.5913	1.691	275
300	417.42	391.9	817.4	1209.3	0.644	1.553	300
325	424.82	399.6	811.9	1211.5	0.696	1.437	325
350	431.90	406.9	806.8	1213.7	0.748	1.337	350
375	438.40	414.2	801.5	1215.7	0.800	1.250	375
400	445.15	421.4	796.3	1217 7	0.853	1.172	400
500	466.57	444.3	779.9	1224 2	1.065	.939	500

TABLE OF PROPERTIES OF SATURATED STEAM.

Temperature in degrees Fahrenheit.	Total pressure above vacuum.	Heat in liquid from 32° in units.	Heat of vaporization, or latent heat in heat units.	Total heat in heat units from water at 32°.	Density or weight of cubic ft. in pounds.	Volume of one pound in cubic feet.	Temperature in degrees Fahrenheit.
32	0.089	0.	1091.7	1091.7	0.0003	3387.	32
60	0.254	28.12	1072.1	1100.2	0.0008	1234.	60
90	0.692	58.04	1051.4	1109.4	0.0021	474.6	90
120	1.683	88.10	1034.4	1118.5	0.0049	204.4	120
140	2.877	108.2	1016.4	1124.6	0.0081	123.2	140
150	3.706	118.3	1009.4	1127.7	0.0103	97.03	150
160	4.729	128.4	1002.3	1130.7	0.0130	77.14	160
170	5.98	138.5	995.3	1133.8	0.0162	61.85	170
180	7.50	148.5	988.3	1136.8	0.0200	50.01	180
190	9.33	158.6	981.3	1139.9	0.0245	40.78	190
200	11.52	168.7	974.2	1142.9	0.0299	33.40	200
210	14.12	178.8	967.2	1146.0	0.0363	27.57	210
220	17.19	188.9	960.1	1149.0	0.0435	22.98	220
225	18.91	193.9	956.7	1150.6	0.0476	20.99	225
230	20.78	198.9	953.2	1152.1	0.0521	19.20	230
235	22.80	204.0	949.6	1153.6	0.0569	17.59	235
240	24.98	209.0	946.1	1155.1	0.0619	16.14	240
245	27.33	214.1	942.6	1156.7	0.0674	14.83	245
250	29.86	219.1	939.1	1158.2	0.0733	13.65	250
255	32.57	224.1	935.6	1159.7	0.0795	12.57	255
260	35.48	229.2	932.0	1161.2	0 0862	11.60	260
265	38.60	234.2	928.6	1162.8	0.0933	10.72	265
270	41.94	239.3	925.0	1164.3	0.1008	9.918	270
275	45.51	244.3	921.5	1165.8	0.1088	9.187	275
280	49.33	249.3	918.0	1167.3	0.1173	8.521	280
285	53.39	254.4	914.5	1168.9	0.1264	7.913	285
290	57.72	259.4	911.0	1170.4	0.1359	7.356	290
295	62.33	264.4	907.4	1171.9	0.1461	6.847	295
300	67.22	269.5	903.9	1173.4	0.1567	6.380	300
305	72.42	274.5	900.5	1175.0	0.1680	5.952	305
310	77.83	279.6	896.9	1176.5	0.1799	5.558	310
315	83.77	284.8	893.2	1178.0	0.1925	5.195	315
320	89.95	290.0	889.5	1179.5	0.2058	4.861	320
325	96.48	295.2	885.9	1181.1	0.2197	4.552	325
330	103.38	300.5	882.1	1128.6	0.2343	4.267	330
335	110.66	305.7	878.4	1184.1	0.2498	4.004	335
340	118.34	310.9	874.7	1185.6	0.2660	3.760	340
345	126.43	316.1	871.1	1187.2	0.2830	3.534	345
350	134.95	321.4	867.3	1188.7	0.3008	3.324	350
355	143.91	326.6	863.6	1190.2	0.3195	3.130	355
360	153.33	331.8	859.9	1191.7	0.3391	2.949	360
365	163.22	337.1	856.2	1193.3	0.3597	2.780	365
370	173.60	342.3	852.5	1194.8	0.3812	2.623	370
375	184.49	347.5	848.8	1196.3	0.4038	2.476	375
380	195.91	352.8	845.0	1197.8	0.4276	2.338	380
385	207.87	358.0	841.4	1199.4	0.4521	2.212	385
390	220.39	363.2	837.7	1200.9	0.4780	2.092	390
395	233.50	368.4	834.0	1202.4	0.5051	1.980	395
400	247.21	373.7	830.2	1203.9	0.5336	1 874	400
405	261.55	378.9	826.6	1205.5	0.5633	1.775	405
410	276.54	384.1	822.9	1207.0	0.5945	1 682	410
415	292.21	389.4	819.1	1208.5	0.6270	1.595	415
420	308.57	394.6	815.4	1210.0	0.6610	1.512	420
425	325.65	399.8	811.8	1211.6	0.6970	1.434	425

saturated steam, one varying with the temperatures, the other with the pressures. The tables are made out in five unit intervals; intermediate points are proportional.

Example.— Suppose we wish to find the total heat corresponding to a pressure of 112.3 pounds (gage). We first add 14.7 to the 112.3 and get 127 pounds absolute pressure. The total heat of 1 pound of steam at 125 pounds pressure is 1,186.9. The total heat at 130 pounds pressure is 1,187.8.

Difference for 5 pounds = 1,187.8 — 1,186.9 = .9
Difference for 1 pound = .9 ÷ 5 = .18
Difference for 2 pounds = 2 × .18 = .36

The total heat for 127 pounds is:

Total heat at 125 pounds = 1,186.9
Difference for 2 pounds = .36
Total heat at 127 pounds = 1,187.26

This method is called interpolation, and in many complete tables the differences for the intervals are given to facilitate the work.

If steam tables are not at hand, there are several approximate formulas that may be used for rough calculations and estimates, but it must be borne in mind that results obtained by the use of these equations are not strictly accurate, and should not be used if the regular tables can be had.

Probably the relation of temperature and pressure will be most frequently needed. If the gage pressure is between 20 pounds and 100 pounds

$$t = 14\sqrt{p} + 198 \text{ approximately} \qquad [3]$$

where t = temperature in degrees Fahrenheit
p = gage pressure in pounds per square inch.

For pressures over 100 pounds per square inch (gage) we must modify the equation thus:

$$t = 14\sqrt{p} + 198\left(\frac{p - 100}{11}\right) \qquad [4]$$

These equations will cover a range of pressures from 20 to 340 pounds, and give an error of less than $1\frac{1}{2}°$ in nearly all cases. From 35 pounds per square inch to 100 pounds the error is generally less than one-half of one degree.

For pressures below 20 pounds use the constant 196 instead of 198.

The latent heat may be approximately expressed by the ormula,

$$l = 1{,}114 - .7\,t \qquad [5]$$

in which l = latent heat

t = temperature in degrees F.

This formula gives very good results for temperatures less than 320°, corresponding to a gage pressure of about 75 pounds. Above this pressure the formula gives slightly larger results than are found in the steam tables. At 250 pounds (gage) the formula gives 829.8 and the steam tables 825.8, so that the error will not be large in any case.

We have defined a B. T. U. as the amount of heat necessary to raise one pound of water from 61° F to 62° F. The specific heat of water is nearly constant over ordinary ranges of temperature and at 400° we find the heat of the liquid from the tables to be 373.7 B. T. U. By definition, the heat of the liquid at 32° is zero, so that a rise of 368° in temperature requires 373.7 B. T. U. If we consider the heat of the liquid proportional to the rise in temperature, our error will be 5.7 units of heat in 400°. At lower temperatures the error is much smaller, so that we may express the heat of the liquid approximately by the formula,

$$h = t - 32 \qquad [6]$$

in which h = the heat of the liquid

t = temperature in degrees as before.

The total heat is equal to the sum of the last two, or

$$H = h + l \qquad [7]$$

The relation of pressure and volume of steam may be approximately expressed by the equation

$$P\,V^n = C, \text{ or } V^n = \frac{C}{P}$$

In which P = absolute pressure

V = specific volume

n = an exponent = $\frac{17}{16}$

C = a constant = 475 nearly.

We may then write the equation

$$V^{\frac{11}{18}} = \frac{475}{P} \text{ or } V = \sqrt[\frac{18}{17}]{\frac{475}{P}} \qquad [8]$$

This is called the equation of constant steam weight; it may be solved by the aid of logarithms.

The density can of course be determined from the specific volume.

Let us apply these approximate formulas to a specific case and see how the results compare with the actual quantities given in the steam tables. For this purpose we will suppose steam at 70.3 pounds gage pressure or 85 pounds absolute.

Equation (8) $t = 14\sqrt{p} + 198$

$= 14\sqrt{70.3} + 198 = 315.40°$

From steam tables, temperature $= 316.02°$

Equation (5) $l = 1{,}114 - .7\,t$

$l = 1{,}114 - (.7 \times 315.4) = 893.2$

From steam tables, latent heat $= 892.5$

Equation (6) $h = t - 32°$

$= 315.6 - 32 = 283.4$

From tables, heat in the liquid $= 285.8$

Equation (7) $H = h + l$

$= 285.8 + 893.2 = 1{,}179.0$

From tables, total heat $= 1{,}178.8$

Equation (8) $V = \sqrt[\frac{18}{17}]{\frac{475}{P}}$

$$V = \sqrt[\frac{18}{17}]{\frac{475}{85}} = 5.051$$

From tables, specific volume . $= 5.125$.

A comparison of these results shows that these formulas cannot be used when accuracy is sought; but if only approximate results are desired they will be found satisfactory. Whenever possible the steam tables should be used in preference to any approximations.

Superheated Vapor. We have seen that a saturated vapor contains just enough heat to keep it in the form of a vapor; if it

loses heat it will condense. A superheated vapor is one that has been heated after vaporization; it can lose this extra heat before any condensation will take place. A vapor in contact with its liquid is saturated; one heated after removal from the liquid is superheated.

For saturated steam there is a fixed temperature for every pressure. If we know either the pressure or the temperature, we can find the other in the steam tables. For instance, if the gage pressure of a boiler is 60.3 pounds and we wish to know the temperature, we simply add atmospheric pressure and turn to our tables and find it to be 307° (about).

With superheated steam the case is entirely different, for there is no longer the same direct relation between the temperature and pressure. In fact, the relation between temperature and pressure of superheated steam depends upon the amount of superheating. Superheated steam at 60.3 pounds gage pressure may have a temperature considerably above 307° F. At a given pressure the temperature and volume of a given weight of superheated steam are always greater than the temperature and volume of the same weight of saturated steam. The properties of superheated steam at given pressure are not constant as is the case with saturated steam.

If superheated steam were a perfect gas, we could determine the relation of P, V and T by the equation $PV = CT$; but superheated steam is not a perfect gas, hence we must modify our equation. By experiment it has been determined that the following equation is nearly correct:

$$PV = 93.5\ T - 971\ P^{\frac{1}{4}}$$

In which P = absolute pressure in pounds per square inch
T = absolute temperature
V = volume of 1 pound in cubic feet.

THE STEAM ENGINE.

We have studied the action and formation of steam, and now we shall consider its application to the steam engine. We know that steam contains a great deal of heat, and that heat can be converted into work by allowing a working substance to pass from the high temperature of the heat generator to the lower tempera-

ture of the refrigerator, during this change giving up heat, which is transformed into work. There are several forms of heat engines, all of which convert the heat contained in some substance into work. At the present time the steam engine is the most important. When of good size and properly designed and run, it is as economical as any other heat engine, and it can be more easily controlled and regulated. We shall consider first the theoretically perfect engine and then the modifications that go to make up the steam engine of to-day.

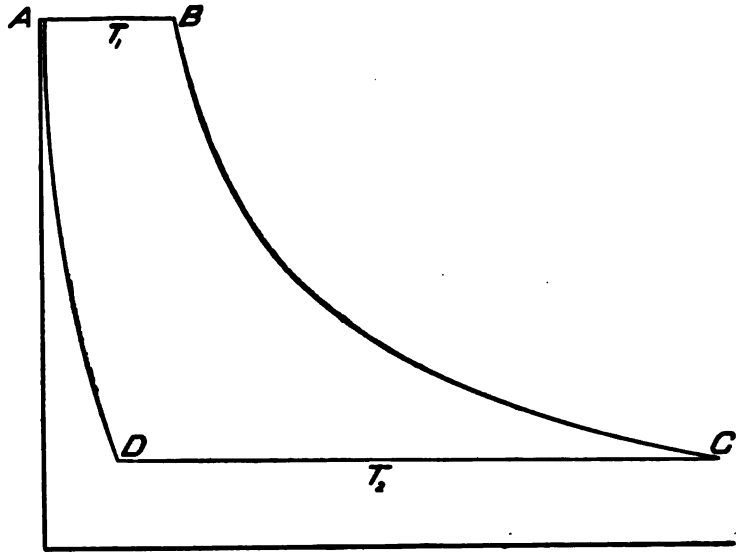


Fig. 3.

The theoretical engine (Fig. 3) is supposed to receive heat from the generator at constant temperature T_1 until communication is interrupted at B. The working substance expands to C without losing or gaining any heat from external sources until the temperature of the refrigerator is reached. The engine now rejects heat at the constant temperature T_2 of the refrigerator and then compresses the working substance without loss or gain in the quantity of heat until the temperature of the heat generator is reached. These are ideal conditions, and, if fulfilled, the efficiency of the perfect engine will depend only on the difference between the tem-

perature at which heat is received and rejected, or, in other words, it depends only upon the difference in temperature between the generator and the refrigerator.

If T_1 = absolute temperature of heat received and

T_2 = absolute temperature of heat rejected, then the thermal efficiency, E, of the engine will be represented by the formula,

$$E = \frac{T_1 - T_2}{T_1}$$

Or, in other words, the efficiency equals the absolute temperature of the heat rejected, subtracted from the absolute temperature of the heat received, and the remainder divided by the absolute temperature of the heat received.

Suppose an engine is supplied with steam at 120 pounds absolute pressure, and the exhaust is at atmospheric pressure. What is the thermal efficiency?

The absolute temperature corresponding to 120 pounds pressure is $341.05 + 461 = 802.05°$, and the absolute temperature of the exhaust is $212 + 461 = 673°$.

$$\text{Then} \quad E = \frac{802.05 - 673}{802.05} = .16, \text{ or } 16 \text{ per cent.}$$

In actual engines this efficiency cannot be realized, because the difference between the heat received and the heat rejected is not all converted into useful work. Part of it is lost by radiation, conduction, condensation, leakage and imperfect action of the valves. The cylinder walls of the theoretical engine are supposed to be made of a nonconducting material, while in the actual engine the walls are of metal, which admits of a ready interchange of heat between cylinder and steam. This action of the walls cannot be overcome, and is so important that a failure to consider its influence will lead to serious errors in computations, and no design can be made intelligently if based on the theory of the engine with nonconducting walls. The theoretical engine carries on its expansion without the loss of any heat, while in the actual engine a large amount of heat is lost by radiation. There is also a considerable loss of pressure between the boiler and engine, due to resistance of flow through pipes and passages. In a slow-speed engine with large and direct ports and valves this trouble may be

minimized. The imperfect action of valve gears may also be lessened with due care, but the action of the cylinder walls still remains to be overcome.

In the theoretical card, admission is at constant boiler pressure, cut-off is sharp and expansion complete, that is, expansion continues until the temperature falls to that of the condenser and the exhaust is at condenser pressure. The piston also sweeps the full length of the cylinder.

In the actual engine there is a considerable loss of pressure between boiler and engine, and the wire-drawing of the ports and valves tends to cause a sloping steam line. Condensation at the beginning of the stroke causes the real expansion line to fall below the theoretical, while re-evaporation causes it to rise above the theoretical toward the end of expansion. In the actual

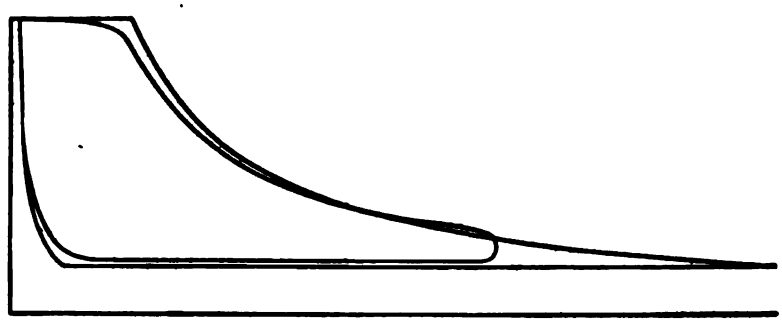


Fig. 4.

engine, release takes place before the end of the stroke, expansion is not complete, that is, the pressure at release is above that of the condenser, and the resistance of exhaust ports causes the back pressure to be above the actual condenser pressure. Moreover, the piston does not sweep the full length of the cylinder, and the clearance space must be filled with steam, which does little or no work. The theoretical and actual cards are shown in Fig. 4.

EFFICIENCY OF THE ACTUAL ENGINE.

We have seen that the efficiency of the theoretical engine is purely a thermal consideration ; the efficiency of the actual engine,

however, is a mechanical matter. The measure of the activity of work is the horse-power which corresponds to the development of 33,000 foot-pounds per minute. As 778 foot-pounds are equivalent to one B. T. U., 33,000 foot-pounds, or one horse-power, is equivalent to $33{,}000 \div 778 = 42.42$ B. T. U. Now if a certain engine uses 84.84 B. T. U. per horse-power per minute, it is evident that its efficiency would only be $\frac{1}{2}$ or 50 per cent, because $42.42 \div 84.84 = \frac{1}{2}$. Hence we may say that the efficiency of the actual engine is equal to $\frac{42.42}{\text{B. T. U. per H. P. per minute}}$. This efficiency is always much less than that of the perfect engine. Let us now discuss the effects of some of the losses.

In the first place, the metal, being a good conductor of heat, becomes heated by the steam within and transmits this heat by conduction and radiation to the air or external bodies. With the cylinder well lagged much less heat is lost by radiation. If the lagging were perfect and the temperature of the cylinder remained the same as the temperature of the steam throughout the stroke, there would be no loss by radiation, but we should still lose heat by conduction to the different parts of the engine.

During expansion, the temperature and pressure of the steam decrease as the volume increases, and the temperature at exhaust is much less than the temperature at admission. In the perfect engine the working substance after exhaust is compressed to the temperature at admission, but in the actual engine much of this steam is lost and the compression of a part of it is incomplete, so that its temperature is less than the temperature at admission.

Suppose an engine is running with admission at 100 pounds absolute and exhaust at 18 pounds absolute. Then from steam tables we find the temperature at admission to be 327.6°, and at exhaust 222.4°. The metal walls of the cylinder, being good conductors and radiators of heat, are cooled by the low temperature of exhaust, so that the entering steam comes through ports and into a cylinder that is more than 100° cooler than the steam. This means that heat must flow from steam to metal until both are of the same temperature. This causes the steam to give up part of its latent heat, and as saturated steam cannot lose any of its heat without condensation, we find the cylinder walls covered with a

film of moisture known as initial condensation. This condensation in simple unjacketed engines working under fair conditions may easily be 25 per cent or more of the entering steam. The moisture in the cylinder has of course the same temperature as the steam; it has simply lost its heat of vaporization.

Although metal is a good conductor of heat it cannot give up nor absorb heat instantly; consequently during expansion the temperature of the steam falls more rapidly than that of the cylinder. This allows heat to flow from the cylinder walls to the moisture on them. As fast as the steam expands so that the pressure in the cylinder becomes less, this condensation will begin to evaporate. As the pressure falls it requires less and less heat to form steam, and therefore more and more of this moisture will be evaporated. At release the pressure drops suddenly, and more heat at once flows from the cylinder walls, and re-evaporation continues throughout the exhaust. Probably all of the water remaining in the cylinder at release is now re-evaporated, blows out into the air or the condenser, and is lost so far as useful work is concerned.

The steam that is first condensed in the cylinder does no work; its heat is used to warm up the cylinder, and later, when it is re-evaporated, it works only during a part of the expansion and at a reduced efficiency, because it is re-evaporated at a pressure and consequently at a temperature very much lower than that of admission. If the cut-off is short, perhaps 20 per cent of the steam condensed may be re-evaporated during expansion; if the cut-off is long, 10 per cent may be re-evaporated, the rest remaining in the cylinder at release still in the form of moisture. Thus some of the entering steam passes through the cylinder as moisture, until after cut-off, and still more passes clear through without doing any work at all.

Suppose an engine is using 30 pounds of steam per horse-power per hour and admission is at 100 pounds absolute. The latent heat of vaporization at this pressure is 884 B. T. U. per pound. If the condensation amounts to 33⅓ per cent, then 10 pounds are condensed and we lose 10 times 884, equals 8,840 B. T. U. per hour, or 147.3 per minute; and since 42.42 B. T. U. represents 1 horse-power, we shall lose by condensation 147.3

divided by 42.42, equals $3\frac{1}{2}$ horse-power (nearly). If the cut-off is shortened, the condensation increases and may amount to 50 per cent at very short cut-off. Of course we use very much less steam at short cut-off than with long cut-off, and doubtless in many cases 50 per cent of the steam at short cut-off is not as great an absolute quantity as 30 per cent at long cut-off. Nevertheless, in all cases it is the percentages that go to make up the efficiency.

In addition to the actual loss from condensation in the cylinder there is still another loss due to the re-evaporation. Suppose, as before, that 10 pounds of steam are condensed in the cylinder, and that 20 per cent of this is re-evaporated during expansion. This will leave 8 pounds to be re-evaporated during exhaust. Suppose the exhaust is at 3 pounds above atmospheric pressure, or 18 pounds absolute (about). Then the heat of vaporization is 958.5 B. T. U. per pound of steam, and it will require 8 times 958.5, which equals 7668.0 B. T. U., to evaporate the 8 pounds. All of this heat is taken from the cylinder, leaving the engine much cooler than it would be were it not for this re-evaporation. This gives some idea of the great amount of heat passing away at exhaust, which is known as the exhaust waste.

In all cylinders it is necessary to have a little space between the cylinder cover and the piston when at the end of the stroke. In vertical engines the space is greater at the bottom than at the top. The volume of this space, together with the volume of the steam ports, is called the clearance. It varies from 1 to 20 per cent, depending upon the type and speed of the engine; the higher the speed, the greater the clearance. This clearance space must be filled with steam before the piston receives full pressure, but this steam does no work except in expanding, and the volume of the clearance offers additional surface for condensation.

Another important loss is that due to friction. We know that it takes considerable power to move an unloaded engine; if fitted with a plain, unbalanced slide valve, the power necessary to move the valve alone is considerable. The piston is made steam tight by packing rings, and leakage around the piston rod is prevented by stuffing boxes. All these devices cause friction as well as wear at the joints. The amount of power wasted in friction varies

greatly, depending upon the kind of valves, general workmanship, state of repair and lubrication.

MULTIPLE EXPANSION.

Two engines may be used together on the same shaft, partly expanding the steam in one of the cylinders, and then passing it over to the other to finish the expansion. One advantage from this arrangement is that the parts can be made lighter. The high-pressure cylinder can be of much less diameter than would be possible if the entire expansion were to take place in one cylinder. This, of course, makes the pressure exerted on the piston rod much less, and the piston rod and connecting rod can thus be made much lighter. The low-pressure cylinder must be larger than it otherwise would be, but its parts need not be much heavier, because the pressure per square inch is always low.

This arrangement gives not only the advantage of lighter parts, but a decided increase of economy over the single cylinder type. If attention is given to the matter, a loss of economy would be expected, because the steam is exposed to a much larger surface through which to lose heat, but the gain comes from another source, and is sufficient to entirely counterbalance the effect of a larger cylinder surface.

When very high pressure steam and a great ratio of expansion is used, the difference between the temperature of the entering and that of the exhaust steam is great. For instance, suppose steam at 160 pounds (gage) pressure enters the cylinder and the exhaust pressure is 2 pounds (gage), the difference in temperature is, from steam tables,

$$370.5° - 218.5° = 152°.$$

This difference becomes nearly 230° if the steam is condensed to about three pounds absolute pressure. The cylinder and ports of the engine are cooled to the low temperature of the exhaust steam, and, as we have seen, a considerable quantity of the entering steam is condensed to give up heat enough to raise the temperature of the cylinder to that of the entering steam. As the ratio of expansion increases, the difference in temperature increases, and consequently the amount of steam thus condensed also increases. To keep this initial condensation

as small as possible we must limit the temperature, that is, we must not have as great a difference between admission and exhaust. To do this we must divide the expansion between two or more cylinders.

It will be remembered that the great trouble Watt found with Newcomen's engine was its great amount of condensation, and he stated as the law which all engines should try to approach, "that the cylinder should be kept as hot as the steam which enters it." This is to avoid condensation when steam first comes in. If, instead of expanding the steam in one cylinder, we expand it partly in one and then finish the expansion in another, we shall have passed it out of the first cylinder before its temperature falls a great deal, and consequently the cylinder walls will be hotter than they would be if we had expanded it entirely in one cylinder. This would then reduce the amount of steam condensed. The importance of this may not be evident at first, but it makes a great difference in the economy of the engine. If there is less condensation, there will be less moisture to re-evaporate, and consequently less exhaust waste; hence we shall save in two ways at the same time.

In a compound engine we admit the steam first to the smaller or high-pressure cylinder, and exhaust it to the larger or low-pressure.

Suppose steam at 160 pounds (gage) pressure is admitted to a cylinder, and the ratio of expansion is such that the steam is exhausted at about 60 pounds (gage) pressure; then the difference of temperature is

$$370.5° - 307° = 63.5°.$$

If, now, the steam when exhausted from the first cylinder enters a second and is allowed to complete its expansion, so that the exhaust pressure is about two pounds (gage) pressure, the difference of temperature in this cylinder will be

$$307° - 218.5° = 88.5°.$$

Then for the single engine, if the exhaust pressure is two pounds (gage), the difference of temperature is 152°, while in the compound engine this difference is divided into two parts,

63.5° and 88.5°. The cylinder condensation for both cylinders of the compound engine will be much less than if the total expansion took place in a single cylinder. The cylinders should be so proportioned that the same quantity of work may be done in each.

If there are two stages of expansion, the engine is called compound, three stages triple, and four quadruple.

Besides reducing the excessive condensation, there is still another gain in using multiple expansion. We have seen how much heat is lost by the exhaust waste, which in the simple

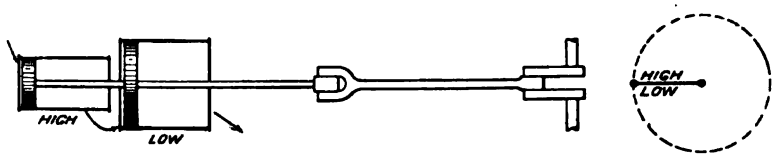


Fig. 5.

engine blows into the air or into the condenser, and is entirely lost. In the multiple expansion engine the exhaust and re-evaporation from one cylinder passes into the next and does work there; any

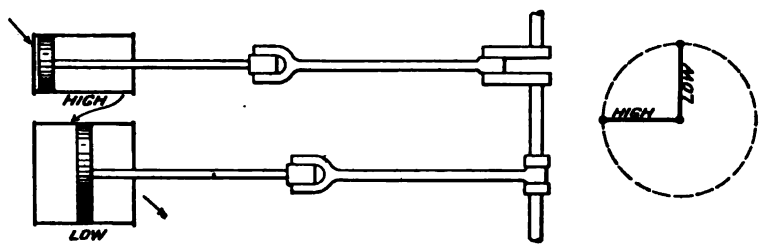


Fig. 6.

leakage from the high pressure is also saved, and does work in the low.

Mechanically there is a decided advantage; the several cranks give a more even turning moment, and the distribution of work between two or more cylinders makes it possible to use lighter individual parts; but there is a disadvantage in having more parts to look after, and a greater first cost of the engine.

Engines having two or more cylinders are arranged in various ways, but only the most common methods will be shown here. For two-cylinder compound engines the cylinders are often placed tandem, as shown in Fig. 5. This has the advantage of having but one crank, connecting rod and crosshead, but it has the disadvantage of dead points. In other words, the turning moment on the shaft is no more uniform than for a simple engine. When the cylinders are placed side by side and the cranks are at right

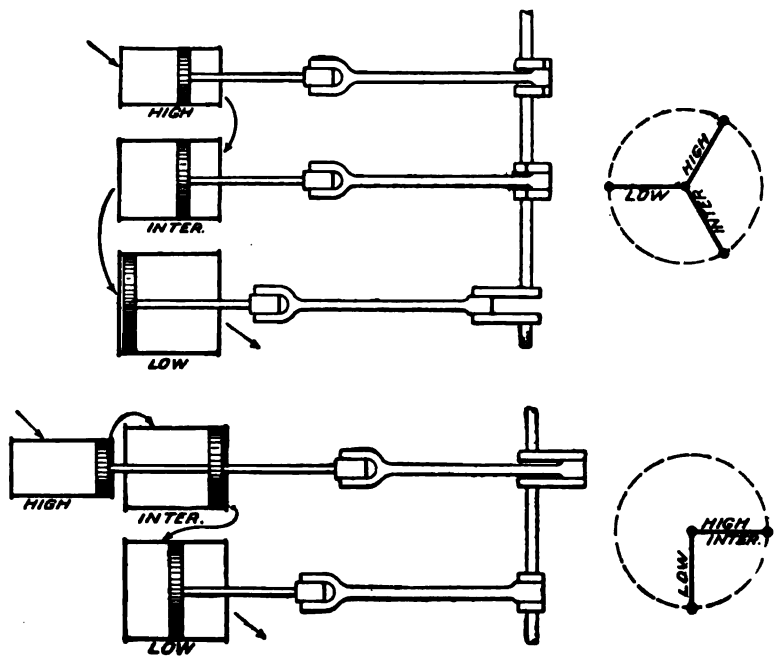


Fig. 7.

angles, as shown in Fig. 6, the low-pressure cylinder cannot receive the exhaust steam directly from the high-pressure cylinder; consequently a receiver must be used. In this case the advantage is due to the even turning moment, and the disadvantage is from the cost of receiver, extra crosshead, crank and connecting rod. In many instances, as electric lighting, marine work, etc., the advantage of the more nearly constant force acting on the shaft is worth far more than the extra first cost. The same may be said

of triple and quadruple expansion engines. (See Fig. 7.) Each type of engine has its special service, and what is suitable in one case may not be serviceable in another. Fig. 8 shows the diagram of a quadruple expansion engine, which is more commonly used in marine work.

JACKETING.

Another method of reducing the loss due to cylinder condensation is to supply heat to the steam while it is in the cylinder.

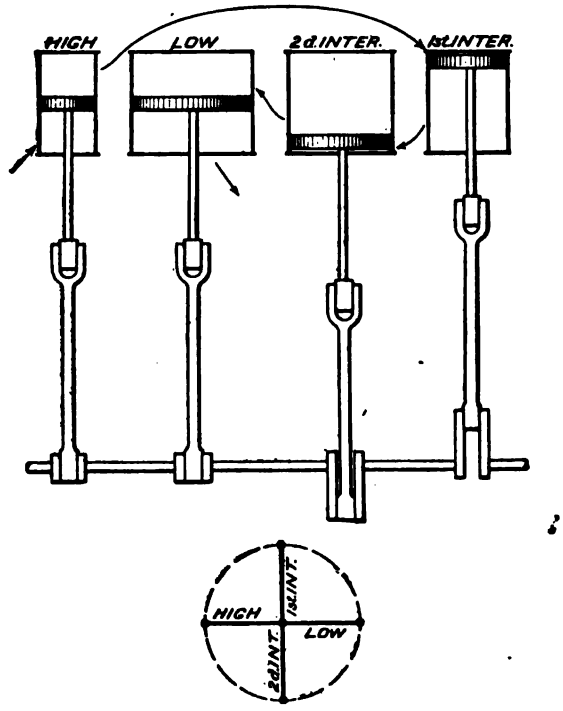


Fig. 8.

This is done by surrounding the cylinder with an iron casting and allowing live steam to circulate in the annular space thus formed. The cylinder covers are also made hollow to permit a circulation of live steam. A cylinder having the annular space (A, Fig. 9) filled with steam is said to be jacketed. A liner, L, is often used in jacketed cylinders.

The function of the jacket is to supply heat to the cylinder walls, to make up for that abstracted during expansion and exhaust, so that at admission the cylinder will be as hot as possible. The result is, that the difference in temperature between the cylinder walls and the entering steam is considerably less than in engines where no jacket is used. Condensation is therefore reduced, and since heat flows from the jacket to the cylinder during expansion, a much larger amount of this condensation is re-evaporated before release and it thus has a chance to do some work in the cylinder. This leaves a comparatively small amount of exhaust waste, and the heat thus abstracted is made good from the steam

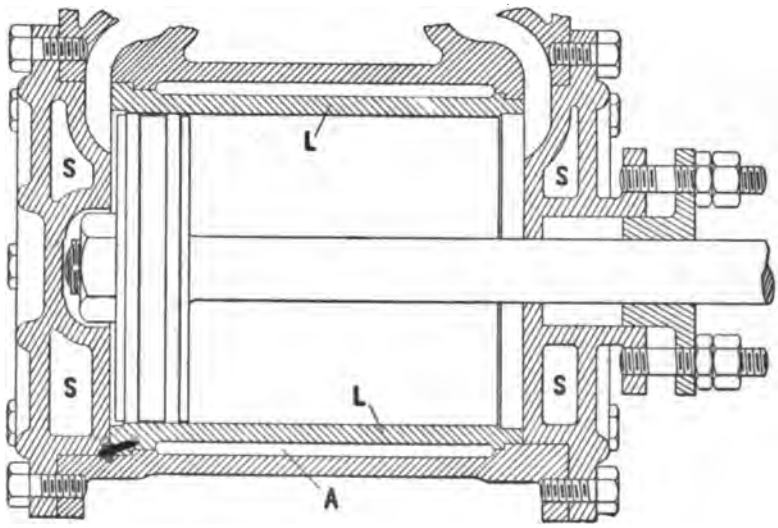


Fig. 9.

in the jacket. Since a large amount of heat is given up by the jacket steam a good deal of it must be condensed. Thus the question is asked: "What is the advantage of this method over that of allowing the entering steam to supply the heat by its own condensation?" This question is answered briefly as follows:

The loss of heat by condensing the steam would be less if the inside of the cylinder could be kept dry. We have seen how the moisture that collects by condensation is re-evaporated during expansion and exhaust, because the pressure falls and the cylinder walls are hotter than the steam. This re-evaporation takes place at the

expense of the heat in the cylinder walls, and they are thus cooled. We have already seen that a great many B. T. U.'s are thus taken from the cylinder and thrown out at exhaust at every stroke. Now if we can keep the inside dry, so that there will be little or no re-evaporation at exhaust, we shall make a considerable saving. The steam that condenses in the jacket does not re-evaporate; it is returned to the boiler as feed water, so that the only heat lost is the latent heat given up during condensation. If the cylinder is heated from within, both the latent heat given up by condensation and the latent heat required for re-evaporation are lost.

In a triple expansion engine there is one distinct advantage in allowing condensation in the cylinder, for this moisture acts as a lubricant, and as the heat of re-evaporation passes into the next cylinder and there does work, there is very little loss. In many marine engines there are no means of lubricating the cylinders at all, the engineers depending entirely upon the condensation.

SUPERHEATED STEAM.

We have already learned that superheated steam contains more heat than is necessary to keep it in the form of steam, and that consequently it can part with some of that heat without condensing.

Suppose this superheated steam is admitted to the cylinder of an engine. We know that the cylinder walls would be comparatively cool, as they were in contact with the exhaust steam and were still further cooled by the re-evaporation of water which was condensed on them at the previous admission of steam. Heat must flow from the steam to the walls until they are as hot as the steam. If the steam were merely saturated, as is usually the case, some of it would be condensed in order to supply this heat to the walls. But in the case of the superheated steam we know heat was given to it beyond that necessary simply to make saturated steam, so that it can give up some heat to the walls before it begins to condense.

Thus the amount of initial condensation is materially reduced, and consequently there will be less cooling of the cylinder walls by the re-evaporation of this condensation; therefore the walls will be hotter at the next admission, and it will require less heat to raise them to the temperature of the incoming steam.

Besides the saving in the engine there is a considerable gain due to the increased efficiency of the boiler, for by superheating, a part of the heat in the waste gases is utilized. If a boiler primes or is so constructed that it does not furnish dry steam, the gain from superheating will be most marked. If there is moisture in the steam and this passes over into the engine, the heat that it contains is entirely wasted, and the re-evaporation of this additional moisture during exhaust causes the cylinder walls to cool off still further.

Suppose we have steam in a boiler at 60 pounds pressure by the gage. Its temperature will be about 307° F. If this steam leaves the boiler by a pipe which passes through a furnace or chimney where the temperature is greater than 307°, it will become heated as it passes through. The pressure will, however, be the same, for it is still in communication with the boiler. This is actually the way in which steam is superheated in practical work.

One great difficulty in superheating is that the superheater, which is usually placed in the uptake, is subjected to a very high temperature and there is great danger of its burning out. The plates of a boiler are not likely to be damaged by the intense heat of the furnace, because the water by its good conducting power prevents their becoming overheated. But steam is a poor conductor of heat, and although the superheater is placed in the uptake or chimney, where the heat is not as intense, they nevertheless cause a great deal of trouble.

Superheating is efficient if low pressure is used, that is, steam at about 50 pounds pressure; but if saturated steam is at 150 to 200 pounds pressure, the temperature is high. If more heat is then added, the temperature becomes such that lubricants are decomposed. In such cases the piston and valve, not being lubricated, cut into the cylinder walls and the valve seat, thus causing leaks and requiring excessive power to move the engine. The packing in the stuffing boxes, unless metallic, is injured and causes considerable trouble. In case high-pressure steam is used the superheating must be slight, often so slight as not to be worth the trouble and expense.

CONDENSERS.

In our study of the theoretical engine on page 20, we learned that to meet the ideal conditions and to attain the maximum efficiency, steam must enter the engine at the constant temperature of the heat generator (or boiler) and must leave the engine at the constant temperature of the refrigerator (or condenser). We have also learned that the difference between the temperature of admission and exhaust is a measure of the thermal efficiency. In Part I of "The Steam Engine," Watt's principle was stated, namely, that "when steam was condensed it should be cooled to as low a temperature as possible." In our discussion of saturated vapors we also learned that the temperature varied with the pressure, and consequently to cool the condensed steam to as low a temperature as possible simply means to condense the steam to as low a pressure as possible.

In the ordinary noncondensing engine, steam cannot be expanded below a pressure of 14.7 pounds, because the atmosphere exerts that pressure at the opening of the exhaust pipe. In fact, this 14.7 pounds is only the theoretical limit, and in practice the exhaust is always a little above this because of resistance in the exhaust ports and exhaust pipe; 17 or even 18 pounds back pressure is more nearly the conditions of actual service.

During the forward stroke, steam expands from the pressure at admission to a much lower pressure at release; then the valve opens for the return stroke and on one side of the piston there is full steam pressure, and on the other side the pressure of exhaust, which acts against the piston and against the force of the incoming steam. If all of this back pressure could be removed so that there would be a vacuum on the exhaust side of the piston, the power of the engine would be increased by just so many pounds of M. E. P., and in addition to this the steam could expand to a very much lower pressure and therefore work with greater economy.

One pound of steam at 17 pounds absolute pressure occupies 23.22 cubic feet of space in the cylinder of the engine, but one pound of water in the condenser occupies only about 0.016 cubic foot, which makes the steam occupy nearly 1,450 times as much space as the water into which it condenses. If, then,

the exhaust steam could be condensed instantly, the back pressure would be reduced almost to zero and the engine would exhaust into a vacuum.

We know that a certain amount of heat is required to change one pound of water at a given temperature into steam at the same temperature; this is called the latent heat, or heat of vaporization. If the steam condenses, it must give up this latent heat. The easiest way of doing this is to let the steam mingle with a spray of water, as in the jet condenser, or come in contact with pipes through which cold water is circulated, as in the surface condenser. These two forms of condenser are fully described in Part I and will not be further considered here.

Unfortunately the mere condensation of the steam will not give a perfect vacuum, because more or less air, which is always in the water, comes over from the boiler and thus gets into the condenser. Moreover, the condensed water is hot, and a vapor rises from it in the condensing chamber; this, together with the air and some leakage, would spoil the vacuum were it not for the air pump, which removes the air and condensed steam. With the best air pump it would be impossible to maintain a perfect vacuum, but a vacuum of 26 inches, which corresponds to about 2 pounds absolute pressure, can readily be maintained in good practice.

Advantages of Condensing. It has already been stated that there is a gain in thermal efficiency by running an engine condensing, but it will be more clearly seen by considering a few figures. The thermal efficiency may be expressed by the formula:

$$E = \frac{T_1 - T_2}{T_1}.$$

This efficiency may be increased by making T_1 larger, which would happen if the boiler pressure were increased, or by making T_2 smaller, which would result from reducing the back pressure by condensing. If the boiler pressure is raised, both the numerator and denominator of the fraction will increase, and the value of the fraction will be but slightly greater. If, however, the back pressure is reduced, the numerator, $T_1 - T_2$, will be larger, while the denominator, T_1, will remain the same. It is apparent that this will cause a much greater increase in efficiency than raising the boiler pressure a like amount.

Suppose an engine is supplied with steam at 85.3 pounds (gage) pressure and it exhausts at 3.3 pounds (gage) pressure. The absolute temperature corresponding to $85.3 + 14.7 = 100$ pounds pressure is $327.58 + 461 = 788.58$, and the absolute temperature corresponding to $3.3 + 14.7 = 18$ pounds pressure is $222.40 + 461 = 683.40$. Then the thermal efficiency will be from the formula:

$$\frac{T_1 - T_2}{T_1} = \frac{788.58 - 683.40}{788.58} = .133 \text{ or } 13.3 \text{ per cent.}$$

If the boiler pressure were raised to 140 pounds absolute the efficiency would be

$$\frac{813.85 - 683.40}{813.85} = .16 \text{ or } 16 \text{ per cent.}$$

If instead of increasing the boiler pressure a condenser is used and thereby the exhaust pressure reduced to 4 pounds (absolute), the efficiency becomes

$$\frac{788.58 - 614.09}{788.58} = .221 = 22.1 \text{ per cent.}$$

Thus we see that if we lower the exhaust pressure 14 pounds we get a greater increase in efficiency than if the boiler pressure is raised 40 pounds.

Another method of showing the advantage by condensing the exhaust is by the indicator card.

Fig. 10 represents a card from a $12'' \times 20''$ engine making 75 revolutions with 75 pounds steam pressure. The dotted diagram represents a card taken when running without a condenser. Cut-off occurs at $\frac{1}{3}$ the stroke. The M. E. P. is 44.2 pounds. Hence the indicated horse-power is about 37.87.

The card shown in full line was taken with the same load, same speed, and with a condenser producing a vacuum of about 26 inches of mercury, which is equal to about 12.7 pounds. The absolute pressure at exhaust is then $14.7 - 12.7 = 2$ pounds. Since the load is the same, the areas and the M. E. P. must be the same in both cases. Cut-off is found to be only about $\frac{1}{5}$ the stroke. The above engine without the condenser uses an amount of steam represented by the length A C, while if a condenser is attached the steam used is represented by the length A C′. Thus

we see that the amount of steam consumed per stroke is considerably less if a condenser is used.

Quantity of Water. Besides merely condensing the steam the injection water cools it still further, so that more than merely the latent heat is removed from it. If exhaust steam enters the condenser at a temperature t_1, it contains a certain amount of heat, which is the *total heat* at that temperature. If it is condensed and cooled to a temperature t_2, at which it leaves the condenser, it then contains a certain amount of heat which is the *heat of the liquid* at this temperature t_2.

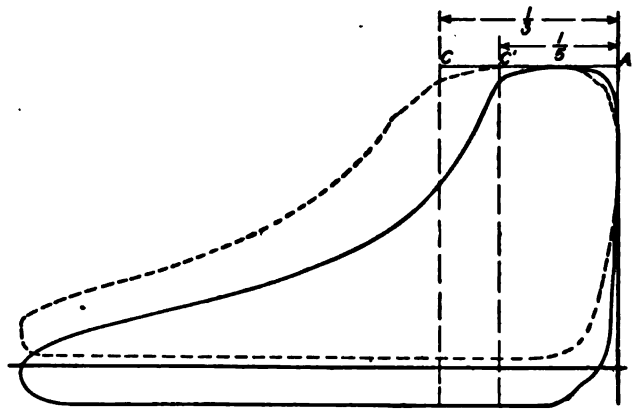


Fig. 10.

If A represents the total heat at t_1, and B represents the heat of the liquid at t_2, then the heat given up by one pound of condensed steam is equal to (A — B) B. T. U., provided the exhaust that enters the condenser is dry saturated steam. If C is the temperature of the injection water, and D is the temperature of the discharge water, then every pound of cooling water absorbs one B. T. U. for every degree rise in temperature; or we may say that the heat absorbed is equal to (D — C) B. T. U. per pound of cooling water. Then it will take as many pounds of water to absorb (A — B) heat units as (D — C) is contained times in (A — B). We may express this in terms of a formula thus:

$$W = \frac{A - B}{D - C}$$

In which W = pounds of cooling water per pound of steam.

For example: Suppose steam is expanded in an engine to 4 pounds absolute pressure. If the temperature of the injection water is 45°, and the condenser is of the surface type with discharge water at 120°, and the temperature of the condensed steam is 130°, how many pounds of injection water are required per pound of steam?

By consulting the steam tables we find the total heat of steam at 4 pounds pressure to be 1,128.6 B. T. U. The heat of the liquid in the condensed steam at 130° is 98.1 B. T. U. Then

$$W = \frac{1{,}128.6 - 98.1}{120 - 45} = 13.74 \text{ pounds.}$$

Suppose steam at 6 pounds absolute pressure exhausts into a jet condenser. The temperature of the injection water is 50° and the discharge is 120°. How many pounds of water are necessary to condense 8 pounds of steam?

In the jet condenser the temperature of the condensed steam and discharge water is the same. We find from the steam tables that the total heat of steam at 6 pounds absolute is 1,138.8 B. T. U., and the heat of the liquid in the condensed steam at 120° is 88.1 B. T. U. Then, as before,

$$W = \frac{1{,}138.8 - 88.1}{120 - 50} = 14.94.$$

For 8 pounds it will take $14.94 \times 8 = 119.52$ pounds.

The above calculation cannot be relied upon to any great extent, for we seldom know the true conditions in the condenser, and it would be of little value to us if we did know, as the exact conditions will change considerably. In practice it is customary to allow for about twice as much water as the above calculation would require. These figures give us a fair idea of the necessary sizes of pipes and passages leading to the condenser, and give a basis for estimating the dimensions of the air pump.

Cooling Surface. The amount of surface required to condense the steam in surface condensers depends upon the efficiency of the metal, the condition of the tubes, the difference in temperature between the two sides and their thickness. There have been no satisfactory tests to determine the amount of cooling surface

necessary for a condenser, and in actual practice there seems to be a wide diversity of opinion. The tubes of a condenser are much thinner than boiler tubes, and much more clean, hence we might expect them to be more efficient in condensing the steam than the boiler tubes are in evaporating it. Boilers may evaporate 7 pounds or more of steam per hour, per square foot of heating surface. Seaton, an eminent authority on marine work, says that with cooling water at 60° F, and the discharge at 120°, a condensation of 13 pounds of steam per square foot per hour is fair average work. A new condenser will of course condense much more than this. If the exhaust pressure is from 6 pounds to 10 pounds absolute, an allowance of 1.5 to 1.8 square feet of cooling surface may be allowed per indicated horse-power, depending upon the pressure. This assumes that the temperatures of the injection and discharge water shall be 60° and 120° respectively.

It is evident that the amount of surface will depend upon the quantity of steam used per hour by the engine, the pressure and temperature of the exhaust and the temperature of the cooling water and discharge. There must also be an allowance for inefficient work after the condenser has become fouled with service. All these conditions make the problem so uncertain that calculations by means of formulæ are likely to be untrustworthy, and it is best at all times to make estimates from the figures given for similar conditions in actual service.

Measurement of Vacuum. We have seen that in order to maintain a vacuum in the condenser it is necessary to pump out, by means of an air pump, the air that leaks in. Evidently, if we are to maintain a proper vacuum, it is necessary to know at all times just how much pressure there is in the condenser. If the pressure increases, the air pump can be run a little faster until the proper vacuum is obtained.

From the study of pneumatics we know that the pressure of the atmosphere can be measured by means of a column of mercury. The atmospheric pressure will support a column of mercury about 30 inches high, which is equivalent to a pressure of 14.7 pounds (nearly). It would be inconvenient to attach a mercury column to the condenser and so we use a gage, in general appearance similar to a boiler gage except that the dial is graduated to read

in inches of mercury instead of in pounds pressure, and it indicates the inches of vacuum *below atmospheric pressure.* If the pointer of the vacuum gage stands at 20, it means that the pressure is equal to 20 inches below atmospheric pressure. Since 30 inches is equal to 14.7 pounds, 20 inches would be equal to $\frac{20}{30} \times 14.7 = 9.8$ pounds. This is 9.8 pounds below atmosphere, or $14.7 - 9.8 = 4.9$ pounds above zero.

If the vacuum gage stands at 26 inches, what is the absolute pressure in the condenser?

$$\frac{26}{30} \times 14.7 = 12.74 \text{ pounds below atmosphere}$$

$$14.7 - 12.74 = 1.96 \text{ pounds absolute pressure.}$$

EXAMPLES FOR PRACTICE.

1. Steam enters the condenser at 11 pounds pressure (absolute). The water enters at 53° and leaves at 110°. The condensed steam leaves at 120°. If the engine uses 26 pounds of steam per horse-power per hour while running at 53 horse-power, what would be the theoretical amount of water used by the condenser and what should be the area of cooling surface of the condenser?

Ans. { 160 square feet. 25,479 pounds.

2. Steam enters a jet condenser at 16 pounds absolute pressure. The injection water has a temperature of 48°. If the temperature of the discharge water is 115°, how many pounds of injection water are necessary per pound of steam?

Ans. 15.89 pounds.

3. If the pointer of a vacuum gage stands at 9, what is the approximate absolute pressure in the condenser?

Ans. 10.3 pounds.

4. The pointer of a vacuum gage which is attached to a condenser stands at 23. What is the approximate pressure in the condenser?

5. The steam gage indicates 175 pounds and the vacuum gage 26 inches of mercury. What is the total difference in pressure?

Ans. 187.74 pounds.

OTHER DEVICES.

Corliss Valves. From a thermal point of view the advantages of the Corliss valve may be summed up in a few words. The exhaust valves are separate from the admission valves and hence the exhaust steam does not come in contact with the admission ports. Thus the admission ports are not cooled and there is less condensation in proportion to the ratio of expansion than in the plain slide valve type of engine. The short ports reduce the volume of clearance and thus save clearance steam and reduce the surface exposed to condensation.

Separator. We have studied the loss of heat due to re-evaporation at exhaust and find that it is considerable. The more moisture there is in the entering steam, the more moisture there will be to re-evaporate; consequently more heat will be lost from the cylinder. It will at once be seen that if we can separate the moisture from the entering steam, we shall keep considerable water out of the cylinder.

PISTON SPEED.

The total distance passed over by the piston in one minute is called the piston speed. As the piston travels the length of the stroke twice for every revolution, the piston speed is evidently equal to the length of stroke multiplied by twice the number of revolutions. Then in the formula for horse-power, $\frac{PLAN}{33{,}000}$,

N = the number of strokes

$L \times N$ = the piston speed.

In case the stroke is stated in inches, the piston speed in feet equals $\frac{L \times N}{12}$.

In determining the allowable piston speed, local conveniences, durability and the character of the work to be done should be considered. Other things being equal, the piston speed increases slightly with an increase in the length of stroke.

The piston speeds in common practice are as follows:

Direct acting pumping engines	100 to 150 feet per minute
Small stationary engines	300 to 500 feet per minute
Large stationary engines	500 to 900 feet per minute
Corliss engines	400 to 800 feet per minute
Locomotives	700 to 1,200 feet per minute
Marine engines	750 to 1,000 feet per minute

RATIO OF EXPANSION.

The ratio of expansion as usually understood is the piston displacement divided by the volume of the cylinder to the point of cut-off. Thus if the piston is 10 inches in diameter and the stroke is 12 inches, the piston displacement is $10^2 \times .7854 \times 12 = 942.48$ cubic inches. If cut-off occurs at $\frac{1}{3}$ the stroke, or when the piston has moved 4 inches, the volume to cut-off is $10^2 \times .7854 \times 4 = 314.16$ cubic inches, and the ratio of expansion is $\frac{942.48}{314.16} = 3$. This may be stated thus:

$$\frac{\text{area of cylinder} \times \text{length of stroke}}{\text{area of cylinder} \times \text{distance to cut-off}} = \text{ratio of expansion.}$$

Since the area of the cylinder appears in both numerator and denominator, we may cancel and write:

$$\text{Ratio of expansion} = \frac{\text{length of stroke}}{\text{distance to cut-off}}.$$

If clearance is taken into account, the true ratio of expansion is different from the apparent ratio as found above. The steam which expands in the cylinder is not merely the volume equal to the piston displacement, but is this volume plus the volume of the clearance.

With a late cut-off and small clearance the true ratio of expansion differs but little from the apparent. But when the cut-off is early and the clearance is large there is considerable difference, as shown in Fig. 11.

In this diagram D E represents the stroke, and is $2\frac{1}{2}$ inches long. D′ D represents the clearance volume, which is equal to $\frac{1}{8}$ the piston displacement, and is therefore .31 inch long. Let cut-off occur at $\frac{1}{8}$ of the stroke; then the apparent ratio of expansion is equal to $\frac{D\,E}{A\,C} = \frac{2\frac{1}{2}}{.31} = 8$. If we consider the clearance, the diagram is changed, as shown by the dotted lines, and the true ratio of expansion is

$$\frac{D'\,E}{A'\,C} = \frac{2.80}{.62} = 4.5.$$

Thus we see that the ratio of expansion is not 8 but 4.5.

WORK DONE IN THE CYLINDER.

The amount of work done per stroke in the engine cylinder is usually found by means of an indicator. It is often desirable, especially in designing engines, to know the work that may be expected under given conditions before the engine is built. The work done in the cylinder is proportional to the mean effective pressure, so that if we are to determine the probable power of our engine we must in some way ascertain the probable mean effective pressure. If the initial pressure, the back pressure and the ratio of expansion are known, we can find the probable M. E. P. by

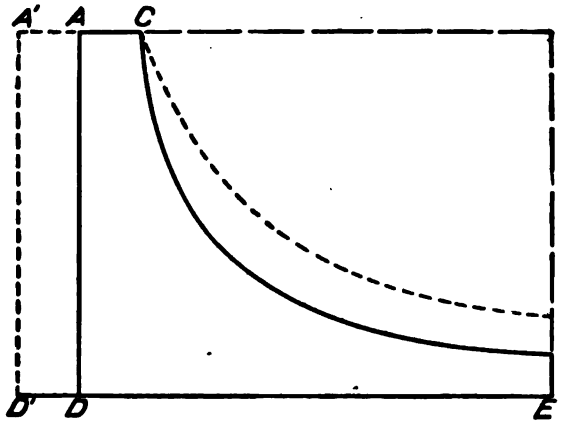


Fig. 11.

means of a formula. This formula does not provide for the losses due to compression, clearance, condensation and leakage, so that the value thus obtained must be multiplied by a factor depending upon the type of engine.

Let P = absolute initial pressure
R = ratio of expansion
p = back pressure (absolute)

Then neglecting all losses, the theoretical M. E. P. will be expressed by the formula,

$$\text{M. E. P.} = \text{P}\,\frac{(1 + \text{hyp. log. R})}{\text{R}} - p.$$

In order to allow for the losses due to compression, clearance

condensation, wire-drawing, etc., it is customary to multiply this value by factors given in the following table:

Engines with special valve gear and independent cut-off valves, about	.90
Plain slide-valve engines	.75 to .90
Compound engines	.65 to .80
Triple expansion engines	.50 to .70

These factors are for unjacketed engines; with jackets the factor might be .05 more in each case. On account of wire-drawing and large compression, high-speed engines would have the smaller value in its respective class. Only the best-designed engines with good valve gears and under favorable conditions will warrant the use of the larger factor in their respective classes. Large engines will of course have larger factors than small engines.

Example.— What is the probable M. E. P. when the initial pressure is 95.3 pounds (gage), the back pressure 3 pounds (absolute) and the ratio of expansion 4? The engine is large, of the plain slide-valve type with steam jackets.

$$P = 95.3 + 14.7 = 110 \text{ pounds}$$
$$p = 3 \text{ pounds}$$
$$R = 4$$

From the following table, hyp. log. R = 1.3863

$$\text{M. E. P.} = \frac{110\,(1 + 1.3863)}{4} - 3$$

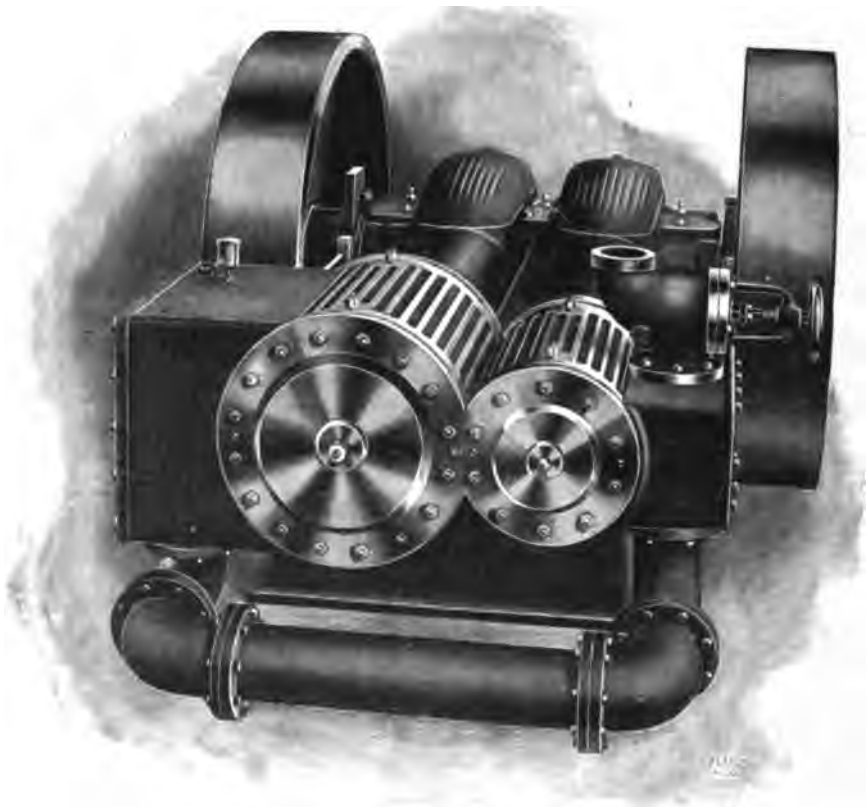
$$= 62.62 \text{ pounds.}$$

For a large plain slide-valve engine, unjacketed, we might expect a factor of .85 to .90, depending upon the conditions. Suppose we call the factor .87, then adding .05 for the effect of the steam jacket we get .92.

$62.62 \times .92 = 57.6$ pounds as the probable M. E. P.

A rough approximation to the power to be expected of a compound, or triple expansion, engine, may be found in a similar manner by assuming that all the expansion takes place in the low-pressure cylinder, neglecting losses as before.

Example.— Find the probable I. H. P. for a triple expansion engine with the following dimensions and data:



CROSS COMPOUND ENGINE

Revolutions,	115 per minute
Initial pressure,	140.3 pounds (gage)
Back pressure,	2 pounds (absolute)
Total ratio of expansion,	12
Diameter of low-pressure cylinder,	60 inches
Stroke,	30 inches

$$\text{M. E. P.} = \frac{P\,(1 + \text{hyp. log. } R)}{R} - p$$

$$= 155\ \frac{(1 + 2.48490)}{12} - 2$$

$$= 43.01.$$

In practice only about .65 of this is actually obtained, so the probable M. E. P. is $.65 \times 43.01 = 27.95$ pounds.

The I. H. P. is now found from the expression $\frac{PLAN}{33{,}000}$ as follows:

$$\text{I. H. P.} = \frac{27.95 \times 2\tfrac{1}{2} \times 2{,}827.4 \times 2 \times 115}{33{,}000} = 1{,}377.$$

TABLE OF HYPERBOLIC OR NAPIERIAN LOGARITHMS.

No.	Log.	No.	Log.	No.	Log.	No.	Log.
1.25	.22314	3.75	1.32175	6.25	1.83258	8.75	2.16905
1.50	.40546	4.00	1.38629	6.50	1.87180	9.00	2.19722
1.75	.55962	4.25	1.44692	6.75	1.90954	9.25	2.22462
2.00	.69315	4.50	1.50407	7.00	1.94591	9.50	2.25129
2.25	.81093	4.75	1.55814	7.25	1.98100	9.75	2.27726
2.50	.91629	5.00	1.60943	7.50	2.01490	10.00	2.30258
2.75	1.01160	5.25	1.65822	7.75	2.04769	12.00	2.48490
3.00	1.09861	5.50	1.70474	8.00	2.07944	15.00	2.70805
3.25	1.17865	5.75	1.74919	8.25	2.11021	18.00	2.89038
3.50	1.25276	6.00	1.79176	8.50	2.14006	20.00	2.99570

CRANK ACTION.

In the steam engine the steam exerts a pressure on the crank pin through the piston rod and connecting rod. When the crank is at the dead center, the entire pressure is on the bearing of the crank shaft; there is no tendency to turn the crank. In any other position the steam pressure tends to turn the crank pin. As the crank pin moves from dead center, the tendency increases until it

reaches a maximum and then decreases until, at the other dead center, it is zero again. If the connecting rod were of infinite length, and steam were admitted throughout the whole stroke, the maximum tendency, or the maximum turning moment as it is called, would occur with the crank at right angles to the line connecting the dead points.

In the actual engine the thrust along the rod is constantly varying even though the pressure on the piston remains the same. This is due to the angularity of the connecting rod. The turning moment is always equal to the thrust along the connecting rod multiplied by the perpendicular distance from the connecting rod to the center of the shaft. If the steam pressure on the piston remains constant, the maximum turning moment occurs

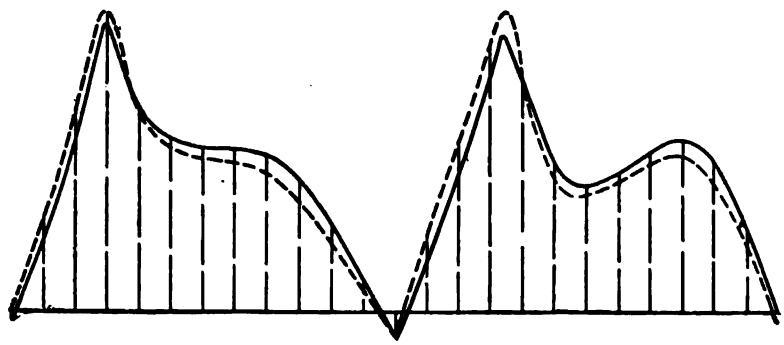


Fig. 12.

when the connecting rod is at right angles to the crank, for in this position the perpendicular distance from rod to center of shaft is a maximum equal to the length of the crank, and as the rod makes its greatest angle with the line connecting the dead center at this point the thrust along it will also be a maximum. If the cut-off is very early, $\frac{1}{4}$ stroke for instance, the maximum thrust along the rod will occur earlier than at the point previously mentioned, but the leverage of the force will be less, so that really there will be little change in the point of maximum turning moment no matter where the cut-off may occur.

To represent this turning moment, diagrams of crank effort are drawn. These diagrams may be drawn with rectangular coordinates having the crank angles represented as abscissae and

the turning moments corresponding to these angles as ordinates.

Besides the thrust of the connecting rod we must take into account friction and the inertia of the reciprocating parts. At first this may be thought of small consequence, but with a fairly heavy piston and connecting rod we can easily see that at high speed the momentum would be great. On a vertical engine, on the up stroke the steam has to lift this heavy mass and impart a very considerable velocity to it, while on the down stroke the acceleration of the mass is added to the steam pressure. This makes the effective force on the up stroke less than that due to the actual steam pressure, and greater on the down stroke. The crank effort diagram represented in Fig. 12 is from a horizontal engine of practical proportions. The initial steam pressure is 50 pounds per square inch. Cut-off at $\frac{1}{6}$ stroke. The engine makes

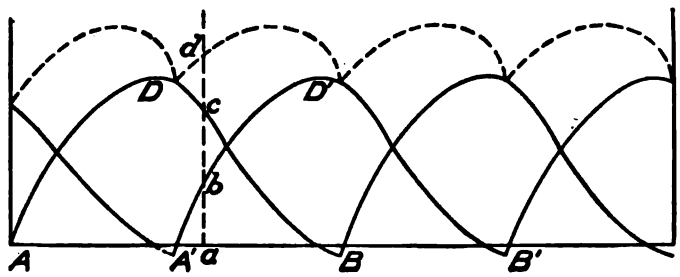


Fig. 13.

240 revolutions per minute. The dotted lines represent the crank effort, without considering friction. The full line is the diagram when weight of moving parts and inertia are considered.

In drawing a crank effort diagram, friction is often neglected, but the effect of inertia of the moving parts is of great importance, especially in the case of high speed.

It has been mentioned in connection with compounding that if there are two or more cranks on the shaft the turning moment is more nearly constant. We can now see that this is so. In Fig. 13, A D B represents the curve of turning moments on one crank, and A′ D′ B′ the curve of turning moments on the other crank, which is at right angles to the first. To find the total turning moment on the shaft the dotted line curve is drawn.

The points are obtained by adding the ordinates. Thus, to find the point *d* add *ac* to *ab*. Then $ad = ac + ab$. It is easily seen that the dotted line curve is more nearly a straight line than the curve A D B.

ECONOMY OF THE STEAM ENGINE.

The effects of various devices and methods employed to increase the economy of the steam engine cannot be studied from the theoretical side alone if we wish to obtain satisfactory results. So complicated and important is the action of the cylinder walls, that if we would learn the conditions favorable to economy we must study the actual tests of engines in service conditions.

Effect of Raising Steam Pressure. In general there is a gain in thermal efficiency by increasing the steam pressure and the total number of expansions, provided proper means are taken to lessen the undesirable effects due to increased condensation and re-evaporation caused by the increased expansion. The initial condensation, of course, places a pretty strict limit upon the number of expansions profitably used in a simple expansion engine.

If we raise the steam pressure and keep the same cut-off, the conditions will be slightly different. The losses from external radiation increase with the rise of steam pressure, but the horse-power increases more rapidly, hence there is a net gain, and since the changes of temperature are greater, the higher the pressure, it is reasonable to suppose that the loss from condensation and re-evaporation will increase. It is not difficult to imagine a point where these losses may offset the gain, and where, indeed, if the pressure is raised too far there will be a net thermal loss. This has actually happened in some cases. At first the gain from raising the steam pressure is rapid. As the pressure rises, the gain increases more slowly, and finally it is not worth the expense, if, indeed, there is not actual loss.

If we bear in mind that there is little gain in economy to be obtained by increasing the steam pressure beyond a certain moderate limit, unless the ratio of expansion is also increased, and that the losses from condensation, re-evaporation and exhaust waste limit the number of expansions profitably used in a simple expansion engine, we shall at once see that we must look to other devices

for decided gains in economy. The most important of these have already been briefly considered.

Superheated Steam. Tests show a very decided gain in economy from using superheated steam, yet practically no permanent results have been obtained, on account of the difficulty of maintaining the superheating apparatus. To superheat to the best advantage we must have a coil of pipe in the flue and thus make use of the otherwise wasted heat. But the intense heat soon burns out the metal and together with the great pressure it is rapidly wasted away. Gains of from 15 per cent to 20 per cent from using superheated steam have actually been observed on simple engines. There has also been some gain noted by the use of superheated steam in triple expansion engines, but the gain is less than in the simple type, because naturally there is less condensation in the triple than in the simple engine.

Steam Jackets supply a small amount of heat to the cylinder during expansion which can be converted into work, but the chief advantage of a jacket is that it keeps the inner walls of the cylinder warmer at admission and thus reduces initial condensation and saves much loss of re-evaporation at exhaust. It will be evident that a large part of the heat of the steam jacket flows to the cylinder during exhaust and is thus entirely lost in the simple engine. In the triple engine this heat passes into the intermediate and low-pressure cylinders; consequently we might expect a greater gain from using a jacket on a triple than on a large simple engine. The main advantage of the jacket has been previously pointed out, and it may be stated that in all cases the gain from the jacket is small and there is to be found a considerable diversity of opinion as to its real advantages. On some engines there is undoubtedly little if any gain. The largest gain is in the smaller engines of say under 200 H. P.; on very small engines the gain is quite large, having been as much as 30 per cent on a $5'' \times 10''$ engine when developing only $1\frac{1}{2}$ H. P. under light load. On a 10 H. P. engine the gain might be as much as 25 per cent. On engines of about 200 H. P. the gain would probably be 5 per cent to 10 per cent for simple condensing and compound condensing, and from 10 per cent to 15 per cent for triple expansion. The saving on large engines, of say 1,000 H. P., is very small, the reason being

that large engines offer less cylinder surface per unit of volume than small ones, and hence we find proportionately less cylinder condensation in large engines than in small ones. The very small engines, in which the gain would be greatest, are seldom jacketed, because they are built for inexpensive machines and the first cost is of more consequence than the later economy.

Compounding is the most effective method of increasing the number of expansions and at the same time avoiding excessive cylinder condensation. We know that increase in boiler pressure and increase in expansion in simple engines are economical only to a certain limit. We shall now discuss the gain due to compounding and the conditions under which it is advantageous.

A direct comparison between tests of different engines is impossible because of the different steam pressures, etc., but a careful study seems to show that for simple condensing engines there is no advantage in raising the steam pressure above 80 pounds. In compounding, the pressure can be advantageously raised to 135 pounds. The gain due to the higher pressure, greater number of expansions and compounding may be 20 per cent to 30 per cent. For triple-expansion engines the most economical steam pressure is of course higher than for compound and may be used to advantage up to 180 pounds or more. The gain from using a triple over a compound may be about 5 to 10 per cent or more. These figures are good only for engines under full load and proper point of cut-off. A compound will usually suffer more loss of economy under light load than a simple, and the triple will suffer more than a compound.

Cut-off and Expansion. The best point for cut-off for a simple engine, whether jacketed or not, is about $\frac{1}{3}$ stroke if the engine is noncondensing and about $\frac{1}{6}$ stroke if condensing. The total expansions of a triple engine or a compound is commonly known as

$$\frac{\text{ratio of low pressure to high pressure}}{\text{fractional part of stroke at cut-off in high}}.$$

For instance, if the cylinders are as 1 : 3 : 8, and cut-off is $\frac{2}{5}$ stroke in high, then the total expansions as conventionally used is $\frac{8}{\frac{2}{5}} = 20$. For the best service of triple engines on land 20

expansions are used. The conditions of service make it impossible to use as many expansions in marine work, hence the relatively poor economy of marine engines. For compound engines 15 expansions seems to be the best in general. Of course it must be understood that the type of engine and conditions of service may necessitate different arrangements, but when such is the case a less economy of steam consumption usually results.

Variation of Load. An engine should be designed to give a fair economy over a reasonable variation of load. Ordinarily if it gives its best economy at normal load there will be a sufficient range. Usually, it happens that the best mechanical efficiency is obtained with a little longer cut-off than that which shows the most economical steam consumption per indicated horse-power. This is because, as the cut-off lengthens, the power increases faster than the frictional losses. It will be evident from this that increasing the cut-off slightly reduces the thermal efficiency, but the gain in mechanical efficiency may offset the thermal loss. Shortening the cut-off causes loss of both thermal and mechanical efficiency. It would then seem that if the engine were given a little longer cut-off than that which would produce the best thermal efficiency at normal load, the power could be reduced with less actual loss. For a slight reduction we should lose mechanical efficiency and gain thermal, and for a slight increase we should gain mechanical and lose thermal. Thus there would be a wider range with good results. There is always more loss by decreasing cut-off below the point of maximum efficiency than by lengthening it. That is, the engine works at a greater disadvantage when running under a light load than when running under a heavy one.

The allowable range of load for a simple engine is greater than for a compound or triple. If the power of a compound is reduced by shortening the cut-off of the high-pressure cylinder without shortening the low proportionally, there is likely to be an uneven distribution of work and, consequently, a wide fluctuation of temperature, which will cause so much condensation as to offset the advantages of compounding. Moreover, the large expansion in the high-pressure cylinder may reduce the admission pressure to the low cylinder so much that the expansion in the low may be carried below the atmosphere in a noncondensing engine and thus

cause a loop at the end of the card, as we have learned in "Steam Engine Indicators." This loop means a loss of power, and that the high-pressure piston is dragging the low and the engine is using up power on itself as it were. A triple engine is even more troublesome than a compound, and besides giving the trouble already mentioned, the dragging of the low-pressure piston may injure the cylinder and loosen the guides. There is little difficulty in increasing the power of a compound or triple. A simple engine may easily be run at reduced power, either by shortening the cut-off or reducing the steam pressure or both.

Effect of Speed. The transfer of heat between the steam and walls of the cylinder, although very rapid, is not instantaneous. The longer the steam can remain in contact with the cylinder walls, the more heat will be lost. Hence it is reasonable to suppose that an increase of speed will reduce condensation. This has been found by tests actually to be the case. Other things being equal, a reasonable increase of speed results in better economy, but as we can seldom get as good a valve motion at high speed, we may lose almost as much in this way as we gain by decreasing our condensation. The most efficient valve gears are to be found on slow-speed engines, and hence we usually find that the most economical engines are slow speed. Nevertheless, with a given valve gear, an increase of speed gives better economy up to the limit of good valve motion. High-speed engines also require more clearance, which means another loss. These two factors, valve motion and clearance, limit our increase of speed beyond a certain point, just as condensation will limit our indefinite increase of boiler pressure.

Feed Water Heaters. The use of feed water heaters has been discussed in the instruction papers on boilers, but it may be well to observe here that in many places where water is expensive condensing engines cannot be run; nevertheless, a very considerable saving can be effected by allowing the exhaust steam to condense in a feed water heater, and thus save the heat that would otherwise be wasted, or the exhaust steam may be used for heating purposes. Of course in such cases the steam consumption of the engine is high, but if proper allowance is made for the heat used for other purposes, the actual fuel consumption rightfully charged to the engine is not excessive. If the feed water is heated by

waste gases, then the gain belongs to the boiler and not to the engine.

The following represents the average steam consumption in pounds per I. H. P. per hour for various types of engine:

Triple expansion stationary	11 to 14 pounds
Triple expansion marine	13 to 16 pounds
Compound stationary	12 to 15 pounds
Compound marine	18 to 21 pounds
Simple condensing	17 to 20 with jacket
Simple condensing	18½ to 22 without jacket
Simple noncondensing	24 to 33 or more

All these figures have been taken from the results of careful tests of engines in actual service, and represent good engines of their respective types.

Direct-acting steam pumps, although very important engines, are extravagant in their consumption of steam. The absence of a fly wheel makes it almost impossible to use steam expansively, and hence the pump takes steam full stroke.

The steam consumption for a simple direct-acting steam pump may be anywhere from 60 to 200 pounds per horse-power per hour, depending upon the size and conditions of service.

The economy of an engine is usually stated in terms of steam per horse-power per hour, or of B. T. U. per horse-power per minute. The latter is more useful for purposes of comparison with other engine tests, but the real criterion of economy is the actual cost of power in terms of fuel consumption, for this can at once be reduced to dollars and cents, and the manufacturer or the builder of the engine can determine the effect of devices for economy in terms of money, which to him is worth more than B. T. U. It may often happen that some expensive device, while effecting a saving of heat consumption, may not save fuel enough to pay for its first cost, owing to the peculiar conditions of service.

TESTING.

The principal object in testing a steam engine is to determine the cost of power or the effect of such conditions as superheating, jacketing, etc., upon the economy of the engine. We must therefore, in the first case, measure the cost of fuel, and in

the second the actual heat used. In either case we must calculate the power of the engine.

The indicated power is determined in the familiar way by means of the indicator, and the actual power by means of a dynamometer or friction brake. (For further particulars of these instruments and apparatus see "Steam Engine Indicators.") To determine the cost of power in terms of coal it is necessary to conduct a careful boiler test, usually of twenty-four hours duration.

When the cost is expressed in terms of steam per horse-power per hour, we may follow either of two methods. We may condense and weigh the exhaust steam, or we may weigh the feed water supplied to the boiler. An hour under favorable conditions is usually sufficient for such tests. Steam used for any purpose other than running the engine must be determined separately and allowed for.

Probably the most accurate terms in which to state the performance of an engine is in B. T. U. per horse-power per minute. When the cost is expressed thus, it is necessary to measure the steam pressure, amount of moisture in the steam, and temperature of condensed steam when it leaves the condenser. Jacket steam must be accounted for separately. Important engines with their boilers, etc., are usually built under contract to give a certain efficiency, and their fulfilment of this contract can be determined only by a complete test of the entire plant. Before beginning the test, the engine should be run for a short time in order to limber it up and get it thoroughly warmed. It is of the utmost importance that all conditions of the test should remain constant, especially the boiler pressure and the load. All instruments used in the test should be tested themselves before being used, in order to determine the effect of any errors to which they may be subject.

Thermometers. All important temperatures, such as feed water, injection water, condensed steam, etc., must be taken by reliable thermometers, the errors of which have been previously determined and allowed for. Good thermometers sold by reliable dealers are usually satisfactory. Thermometers with detachable scales are subject to serious errors, and should be used only for very crude work. Cheap thermometers are of little value in an engine test.

Indicators. The most important and least satisfactory instrument used in the test is the indicator. It is subject to an error of 2 per cent or 3 per cent at low speed, and this may easily be two or three times as much at high speed. It does not work satisfactorily at more than 400 revolutions per minute. If the indicator is carefully tested under conditions similar to those on the engine, the errors may be reduced to a minimum, but there will always be some uncertainty. The principal errors to which the indicator is subject have been mentioned in the instruction paper on "Steam Engine Indicators." It may, however, be well to add that for accurate work we should always use two indicators, as the long piping and joints necessary for only one causes a considerable loss of pressure and much condensation. For marine work it is customary to use only one indicator, with a three-way cock, the lower end of the cylinder usually being inaccessible.

Scales. Weighing should be done on standard platform scales. The water may be weighed in barrels provided with large drain valves which will allow the water to run out quickly. It is seldom possible to drain barrels completely, and so it is best to let out what will run freely, then shut the valve and weigh the barrel. This we call "empty" weight, and deducted from the weight "full," evidently gives us the true weight of water.

If not convenient to weigh the water, it may be measured in tanks or receptacles of known capacity, and the temperature taken, allowing the proper weight per cubic foot for water at that temperature; or it may be determined by meters.

Meters. Water meters are of two kinds, those that record the amount of water by displacement of a piston, and those in which the flow is recorded by means of a rotating disc. Piston water meters can be made very accurate, and if working under fair conditions of service they may be relied upon to a close degree. The chief error in a meter arises from the air that may be in the water. To reduce this error to a minimum, the meter should be vented, to allow the air to escape without passing through the meter. Rotary meters are good enough for very rough work, but are seldom sufficiently accurate for a careful engine test. So far as possible, weirs should not be used in engine work. They may be fairly accurate under certain conditions,

LOG OF TEST.

Time of Observation.	Revolutions.	M. E. P.	Pressures.				Temperatures.			Weights.		
			Boiler.	1st Receiver.	2d Receiver.	Condenser.	Feed Water.	Injection Water.	Condenser Discharge.	Coal.	Injection Water.	Discharge Water.

but a very little oil in the water may affect them seriously. They may sometimes be used to measure the discharge from a jet condenser, for then the volume is so large that the actual error is proportionately small.

Gages. Pressures should be measured on good gages that have been recently tested by comparison with a mercury column. The atmospheric pressure should be read from the barometer, and for accurate work this pressure should be used. For ordinary work, 30 inches, or 14.7 pounds, will do.

Calorimeter. When using superheated steam it is sufficient to take the temperature and pressure in the steam pipe, but if saturated steam is used, we must determine the amount of moisture it contains. This is done by means of a calorimeter such as described in "Boiler Accessories."

Brake. Any of the forms of friction brake described in "Steam Engine Indicators" will answer the purpose. For smooth and continuous running it is essential that the brake and its band be cooled by a continuous stream of water. The water may either circulate in the rim of the wheel or around the brake band, but it must not come in contact with the rubbing surfaces.

If the load is steady, seven or eight observations at equal intervals will usually be sufficient. If possible, the cards should be taken simultaneously, and then all the data averaged for the final result. If the load fluctuates, the cards must be taken oftener, and a greater number of observations will be required. The greatest care and accuracy must be used in all this work. In conducting a test, a careful log should be kept of the data; the outline given on page 56 being a suggestion.

THE STEAM TURBINE.

A description of the steam turbine and the general principles of the engine were given in Part I of "The Steam Engine." Now we shall discuss its efficiency. The turbine is such a comparatively new engine that there have been but few tests made, and consequently we know very much less about its possibilities than is the case with the ordinary reciprocating engine.

Probably the greatest loss in the reciprocating engine is that due to condensation and the subsequent re-evaporation at exhaust.

The exhaust cools the cylinder, so that the incoming steam meets cool walls, while in the turbine no such conditions exist. The admission takes place at one end of the engine and the exhaust occurs at the other end. The temperature gradually falls from admission to exhaust and the expanded steam never comes in contact with the part in which the higher-pressure steam works. Thus Watt's principle seems to be fulfilled, namely, "The cylinder should always be as hot as the steam that enters it." Of course there is considerable loss from radiation, but there should be very much less condensation than in the reciprocating type.

Superheating may be made use of with considerable gain in economy. There are no rubbing surfaces, no lubricants to decompose and no glands to burn out, as is the case in the reciprocating engine. The steam may be superheated to 60° or more to advantage. There being no internal lubrication, there is of course no oil to get into the condenser, and so the feed water may be used without fear of getting grease into the boiler.

Another advantage seems to be in the more complete expansion of the steam. There is little gain in the reciprocating engine by expanding the steam beyond a certain limit, because of the increased condensation. The boiler pressure cannot be increased indefinitely, neither can the expansion be carried out to the limit.

From these considerations it would seem as if the turbine ought to show much better efficiency than the reciprocating engine, and were it not for the friction of steam against the vanes of the turbine the advantage would doubtless be in its favor. Tests have shown a consumption of about 16 pounds of steam per B. H. P. per hour. Assuming an efficiency of 85 per cent, this would give about 14 pounds per I. H. P. per hour. Tests of the best modern triple expansion pumping engines have shown a steam consumption of a little over 11 pounds per I. H. P., and numerous tests of ordinary triple expansion engines have been made which show a consumption of 12 to 13 pounds.

The most recent test of which we have accurate knowledge was made on a Westinghouse-Parsons engine of 600 H. P. when running at 3,600 revolutions per minute. With ordinary steam having 3 per cent of priming, the turbine used 15.5 pounds of steam per B. H. P. per hour with a vacuum of 25$\frac{7}{8}$ inches in the

condenser. With 30° of superheating and 26½ inches of vacuum, the steam consumption fell to 14.2 pounds. Assuming 85 per cent mechanical efficiency as before would give a relative steam consumption of 13.17 pounds per I. H.P. in the first case, and 12.07 pounds in the second case. It will be instructive to compare these figures with those given for reciprocating engines on page 53.

SECTION 7.

AUTOMOBILES.

The conception of the automobile, as it is generally understood, is no new thing, if we take it to mean a self-propelled vehicle moving over an ordinary road or highway. In fact, the first operative automobile antedated the locomotive by many years, both in conception and execution. The locomotive, however, differs from the automobile only in that it is designed to run upon rails over a given route, while the automobile is so constructed as to run wherever obstacles or the configuration of the surface of the ground do not prevent.

As the use of rails even for short haulage about mines was not extensive before the opening of the nineteenth century, and as the expense of a private right-of-way, coupled to the cost of grading and track laying, acted as a very decided detergent on investments in railroad work before the possibilities of the system had been exploited and demonstrated, it is very natural that the first thought of designers of power-propelled vehicles should have turned toward automobile construction when the availability of steam for the purpose was first fully realized in the last half of the eighteenth century.

It is probable, too, that had the public roads been better, the steam automobile might have advanced to a wide range of usefulness, side by side with the locomotive, instead of waiting for more than a century for what may be considered a real recognition.

The automobile was foreshadowed in the thirteenth century by a vehicle propelled by a type of Hero or reaction engine, and was foretold in the fourteenth century by Roger Bacon in an indefinite way, just as any other inconceivable thing might be prophesied without fear of contradiction.

Although the road locomotive was suggested to Watt in 1759, he was too busy to work it up, and it was not until ten years later that the first working automobile operated by a steam engine was built by Cugnot in France. It was worked long

enough to develop its weaknesses and a year later, in 1770, an improved vehicle like that shown in Fig. 1 was built. This engine is still preserved at the Conservatoire des Arts et Metiers, in Paris.

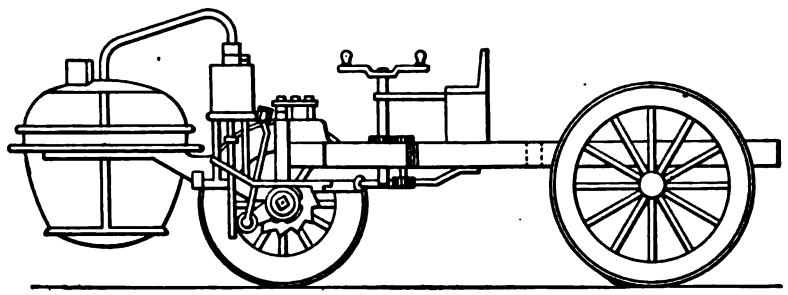


Fig. 1. Cugnot's Car.

The boiler was of copper, with an internal firebox and two copper flues, and was placed at the front, overhanging the forward axle. The engine consisted of two single-acting cylinders driving a pawl that engaged in a ratchet attached to the axle of the single driving wheel 50 inches in diameter, giving the latter a quarter revolution at each stroke.

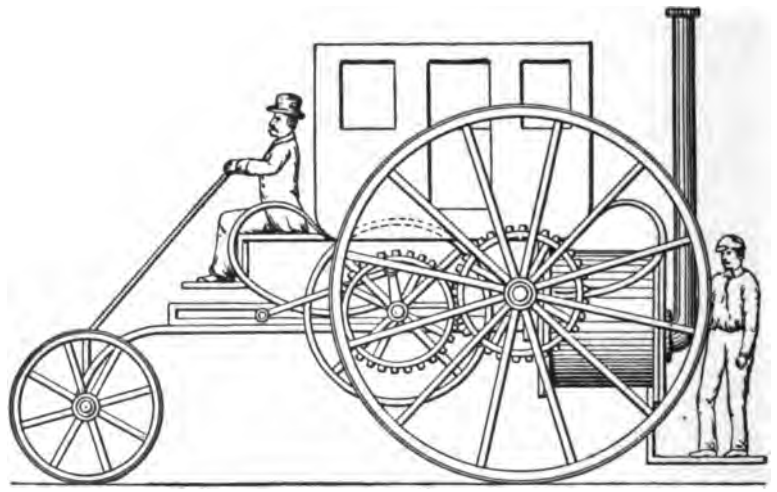


Fig. 2. Trevethick's Road Carriage.

While this engine attracted considerable attention in military circles its general usefulness was not recognized and its development was carried no farther. This was followed, however, by a

few sporadic attempts at automobile work, but without accomplishing any valuable results. In 1802 Richard Trevethick built the steam road carriage illustrated in Fig. 2. The motive power consisted of a boiler and a single-cylinder engine carried on the rear axle, and driving the latter through a crank and gearing. The forward end was carried by a pair of smaller wheels, which served to guide the machine through the intermediary of a lever, as shown in the engraving. This carriage was worked for a time in and about London, but did not prove to be a drawing card with the public, and was soon dismantled and the engine used for mill purposes.

During the period of the Napoleonic wars little or nothing was done in the development of the automobile, but in the twenties

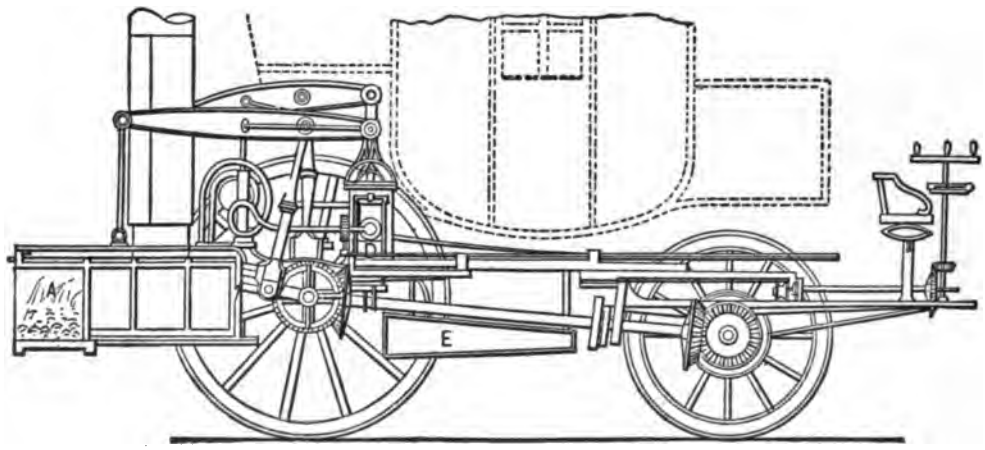


Fig. 3. Steam Vehicle of 1825.

some experiments were made, and carriages built, using a push foot as the means of propulsion. These were unsuccessful, but in 1825 a vehicle was brought out that possessed some of the elements of success, though it did not fully meet all of the requirements of the case.

Its general construction is shown in Fig. 3, in which the boiler, shown at A, is formed of a cast-iron flue encased in a wrought-iron or copper shell. The cylinders are at D, and are double acting, driving short walking beams to which the connecting rods were attached.

A tank, E, beneath the body, served to carry the water supply.

The four wheels were attached to the axles in nearly the same manner as in common coaches, except that there was a ratchet wheel formed on the back part of the same, with a box wedged upon the axle containing a dog, or pawl, with a spring whereby the wheels were made to turn with the axle and at the same time the outer one was allowed to travel faster than the inner on curves. It was not, however, until 1829 that the first really successful road carriage was built. This was done by W. H. James, by whom a speed of fifteen miles an hour was attained.

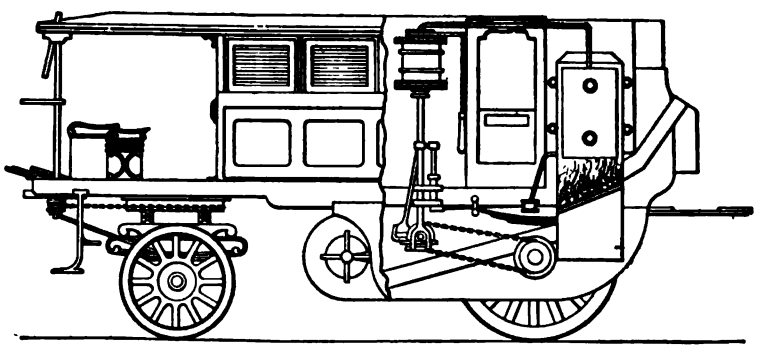


Fig. 4. Hancock's Steam Omnibus of 1839.

Ten years later, in 1839, a man by the name of Hancock built a number of steam vehicles, among which was the omnibus shown in Fig. 4. These at once took the lead in England, and lines were formed running out to Paddington, Islington and other suburban places from London.

The omnibus carried a vertical tubular boiler having a magazine from which the fuel was fed into the furnace, the fire being controlled and varied in intensity by the use of a blower. The engine was of the inverted vertical type with a chain drive, thus anticipating some of the most modern machines.

These vehicles were closely followed by a number of carriages built by J. Scott Russell, and which were run in the neighborhood of London and in Scotland. Some of these automobiles attained a speed of from twelve to fifteen miles per hour on good roads. There was great hostility to this method of propulsion, however,

and in one case it reached such a point that a carriage was destroyed. Still one of them continued on the roads until 1857.

The next point of development lay in the direction of traction engines, and from 1860 on a great deal of attention was paid to this branch of the subject, especially in England, where many machines were built, many of them of fine design and of first-class efficiency.

This work was accompanied by a steady and healthy development, until the construction of traction engines became a regularly established business.

With the perfection of the gas or internal combustion engine for shop purposes the possibility of its adaptation to vehicle propulsion became apparent, and many designers turned their attention in that direction. This was especially true in France, and during the early nineties many trials and failures were consummated. Still the failures were so intermingled with partial successes as to encourage a continuance of the work, until the matter attracted public attention and elicited favorable criticisms from the press. The value of such a vehicle was so apparent from every point of view that numerous prizes were offered as a stimulus to greater and better endeavors on the part of the designers.

These trials followed each other with such frequency and became so numerous that it will be quite impossible to give even a list of them all, a few only being indicated to convey an idea of the trials and the rewards therefor.

One of the first to attract wide attention was a trial instituted in 1896 by the "Engineer" of London, which offered a prize of 1,100 guineas for the best motor car that should fulfil certain conditions.

The trial was to include a run to Birmingham and return. The first date for the competition was set for October, 1896, but owing to the numerous requests from possible competitors, it was postponed to June, 1897. At that time there were seventy-two entries, but upon the day set for the trial only seven competitors were on the ground, and of these but five were ready for work. The judges, who were among the most prominent engineers in England, made a careful examination of all of the motor cars sub-

mitted, but decided that none of them met the requirements of what such a vehicle should be, and so refused to award the prize. From this it was assumed that in June, 1897, there was no such thing as an automobile industry in England. This, however, must be taken with some reservation on account of the hostile attitude assumed by the "Engineer" in reference to vehicles using light oil, though a $500 prize was afterwards offered for them. But it should not be considered surprising that none were offered in competition.

Closely following the failure of the scheme of the "Engineer" in England there was a competition at Paris in August, 1897, for heavy-weight vehicles. These were divided into two groups:

1. The carriage of passengers, the vehicles accommodating

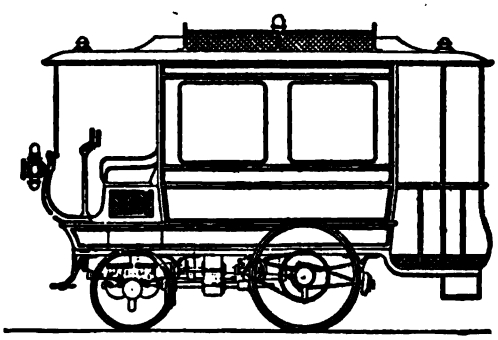


Fig. 5. Panhard Omnibus.

at least ten persons and six hundred pounds of baggage.

2. The carriage of freight and the simultaneous carriage of passengers and freight, with a minimum weight of one ton.

The total distance of the run over which the vehicles were sent was 183½ miles, thirty-three of which were over paved roads. In this competition seven manufacturers were represented, and of these several carriages were capable of a normal and assured operation.

Of the vehicles tested in this trial, some like the Scotte, were intended for the double purpose of carrying a load and, at the same time, hauling a trailing car.

The Panhard omnibus shown in Fig. 5 is a fair sample of the type submitted at that time. It carried ten passengers and 180 pounds of baggage. It is provided with two coupled Daimler-

Phenix vertical gasoline motors of six horse-power, so that in reality it is a four-cylinder, twelve-horse-power motor, which is placed under the front seat, and actuates the hind wheels. The transmission is effected through gearings and chains with four differential speeds.

The weight in running order is 7,920 pounds. The speed on a level reached ten miles an hour, while the average, including all stoppages, was about five miles per hour. This trial evidently had the desired effect as far as a stimulus was concerned, for in June, 1898, there was a competition at Paris of hackney coaches, in which twenty-six vehicles were entered, representing twelve manufacturers. Out of these twenty-six vehicles sixteen were electric and ten gasoline.

In general outline and appearance the carriages submitted to this trial did not differ in essential particulars from those that have since come into extensive use, and which, developed in a natural evolution from the earlier vehicles, were, in themselves, commercial and mechanical successes.

It will be readily understood, however, that the problem of constructing light automobiles for pleasure carriages is comparatively easy beside that of building a vehicle for heavy traffic, especially if the latter is to be worked over rough country roads. It was to encourage this branch of the work that trials were held and prizes awarded for vehicles of this character near Liverpool in 1898 and 1899.

The chief object of this trial was "to encourage the development of types of heavy motor wagons, suitable for trade and agriculture requirements in the neighborhood of Liverpool, which will be capable of economically taking the place of horse haulage, and of competing with existing railway rates in the transportation of heavy loads of goods over distances of up to forty miles. Further objects were to afford motor vehicle builders an opportunity of demonstrating their ability to overcome the faults developed during the 1898 trials, to determine the progress being made in the country upon heavy automobilism, and to apply certain special tests recommended in the first report."

It was decided, in order to have exact comparisons, to relinquish the idea of running to Manchester and to adhere to the

routes covered in the 1898 trials. Each of these routes was between thirty-five and thirty-six miles in length, and corresponded to the distance between Liverpool and many manufacturing towns in South and East Lancashire. The routes were announced prior to the competition, and it was open to any competitor to ride over them if he chose. They comprised some of the worst roads in Lancashire.

Elaborate rules and conditions were laid down and the whole affair was managed in an admirable manner. No award was made in Class A, which included very light vehicles, but in Class B, which included wagons capable of carrying a minimum load of three and one-half tons, with a minimum platform area of sixty-five square feet, gold and silver medals were awarded.

These instances go to show the character of the trials alluded to, which do not include the long-distance racing tests, which will be touched upon later.

The result was that by the end of 1899 automobilism had been firmly established. Frequent trials of both public and private character had demonstrated that road locomotion by automobile vehicles is possible; that it is accompanied by no greater dangers than with the horse-drawn vehicle; that the motor is no more liable to breakdowns when in the hands of competent persons, and that the expense of maintenance is less than with horse-drawn carriages. From that time on there was an uninterrupted improvement in all classes of vehicles; improvements in general design as well as in detail, and this will, of course, continue to the end of the chapter.

With this introduction to the general subject we may now turn to the discussion of the various details that go to make up a successful automobile. The first and most important of these is the motor. During the first one hundred years, commencing with the exploitation of Cugnot's machine, steam was the only motive power that was available for the work. When, however, the gas engine had been so far developed that the internal combustion engine using oil was available, this at once became the formidable competitor of steam, to be closely followed by electricity when the storage battery had been so perfected as to be reliable for general use.

For internal combustion motors, as well as for the generation of steam for engines, gasoline is now the standard and recognized fuel of common practice.

The work that has been done on these motors is almost infinite in its variety and extent.

It will be difficult to mention a gas or combustible oil with which experiments have not been tried in internal combustion motors. Gasoline is by far the most popular, though some of the heavier oils, such as kerosene, have been successfully used. For automobile work the gases have been practically disregarded on account of the space and weight required for storage, to which must be added the expense for compression. Some experiments have been made with acetylene, though they have not given such results as to encourage the idea that it will be immediately available for automobile work without further extended investigations, and there is still a difference of opinion as to the expediency of even attempting to use it.

Some tests were made by Cunat with engines of from eight to sixteen horse-power using acetylene, with no other change than to diminish the size of the inlet valve. When using a mixture of ten of air to one of gas, acetylene gave three times the energy of an equal volume of coal gas, developing a horse-power for six cents per hour.

In other experiments a two-horse-power motor was able to develop a horse-power hour on 6.35 cubic feet of acetylene, using a mixture of fifteen of air to one of gas. This gave about 2.1 times the energy of coal gas. In another case it was impossible to use a greater proportion of gas than five per cent on account of the high compression, and here, while the explosion pressure was extremely great, the fall of pressure was immediate and expansion was not carried out.

The following points regarding the behavior of the gas need to be especially noted:

1. The low ignition temperature.
2. The great rapidity of the transmission of flame.
3. The high combustion temperature.
4. The extraordinary energy evolved by the explosion.
5. The wide range of its explosive mixtures.

It is evident, then, that to avoid premature explosions the cylinder must be kept at a temperature below that of the ignition of the mixture when compressed, and this necessitates a water-jacket cylinder, even in small sizes, on account of the extremely high temperature of the combustion. On the other hand, the low temperature of the cylinder walls would greatly lessen the effective pressure of the expansion, as the cooling effect on the gas would be very marked. The only way to increase the efficiency would be to increase the speed of rotation, thus giving less time for an exchange of heat between the gas and the cylinder walls.

That acetylene may be used as a motive power is assured, but whether it will prove popular cannot now be stated. It has many of the desirable qualities of gasoline, but at present it is more expensive, and the motor in which it is used would probably be subjected to more wear, and consequently more repair, than if used with its milder rival. Hence, considerable time must first be spent in experimental work before the acetylene motor can be considered commercially in the field.

One of the first requirements for a successful automobile engine is that it should be economical, though even this, in the case of pleasure vehicles, can be sacrificed to other considerations. A more important one is, that it should have a reasonably long period of service without requiring a replenishment of fuel, whether this take the form of fresh supplies of gasoline or a recharging of the batteries of an electric vehicle. Of course it goes without saying that the motor should be compact and light, but even these two features, essential as they may be, should be sacrificed to accessibility for inspection and repairs. This last feature cannot be too strongly insisted upon, especially where the vehicle is to be used for touring purposes. Any and every class of machinery is subject to failure, as the result of ordinary wear and tear or excessive stresses accidentally applied, and the breakdown of an automobile upon the road, always aggravating and annoying, becomes doubly so when, in the absence of first-class shop facilities, the mechanism is so designed that the disabled part cannot be readily removed and repaired.

Again, while a light weight should be the end aimed at by every designer, it should not permit him to lose sight of the necessity for ample strength.

Finally, the ideal motor should be silent and free from vibration. These two requirements are met in the electric motor, but in the case of a gasoline or steam engine, both noise and vibration are exceedingly difficult to overcome. As for the noise due to the exhaust, that depends upon the completeness of the combustion and the freedom with which, when the gases have done their work, they are allowed to escape into the atmosphere. As for the vibration, this will be excessive and disagreeable in one-cylinder engines, but can be to a great extent eliminated by the use of two cylinders whose cranks are set opposite to each other. This, however, has a disadvantage, in that a fly-wheel is needed, as in the single-cylinder machine, in order to maintain anything like a uniform torque upon the driving shaft. Three or four cylinders, with the crank separated by equal angles, can probably be made to give the best results as far as vibration is concerned, though adding considerably to the cost and maintenance of the machinery.

The advocates of the use of steam for heavy trucks claim a superiority for that method of applying the power, on the ground that it can be economically operated with heavier loads and throughout a greater radius of action than any other class of motor, and that it is independent of charging stations and its supplies are easily and rapidly taken on board.

In regard to the development of the gasoline internal combustion motor, it has probably received the lion's share of attention. In 1898 there was a marked tendency on the part of manufacturers of gasoline motors for automobiles to do away with the cooling of the cylinder by a circulation of water, and to replace it either by an energetic ventilation with a fan driven by the motor, whose speed increased with that of the motor, or by enlarging the radiating surfaces. At that time the gasoline motor was by long odds the favorite motive power for road vehicles, but its supremacy for city and suburban work was being contested by both steam and electricity.

In the course of this work gasoline motors have been built that in regular road service have developed a horse-power on a consumption of fifteen gallons per hour.

A development of the internal combustion motor along another line was shown at the Paris Automobile and Cycle Show of

1901, which was marked by an attempt on the part of French manufacturers to so exploit the alcohol motor as to enable it to take the place of the gasoline. It is, of course, possible to construct an alcohol motor suitable for automobile work, but it has not thus far been done in a way that is satisfactory to either builder or user.

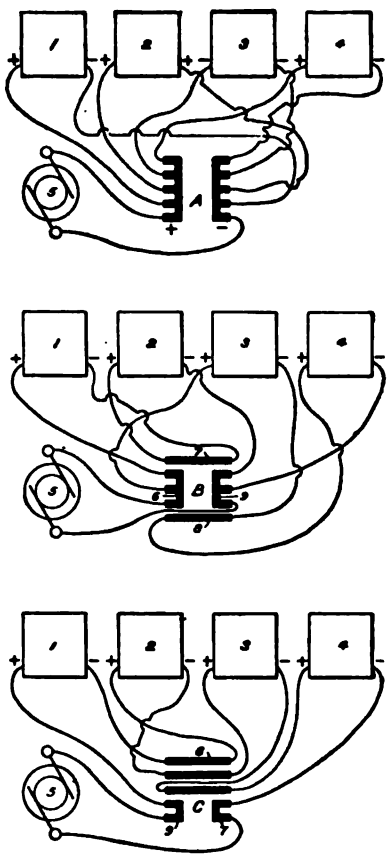


Fig. 6. Connections Between Storage Batteries and Motor on Electric Vehicles.

Returning now to the competition with gasoline by steam and electricity; the principal manifestation of activity in the latter was found in the promotion of electric hacks. In order that these might prove commercially successful, it was necessary that they should be put out upon a large scale, since the horse-drawn vehicle did not have to meet such severe economic exigencies. This was done, and the success of the electric vehicle, even for other designs, became an accomplished fact.

The availability of the electric vehicle for touring purposes has often been questioned, and there can be no doubt that it does not lend itself as readily to the purpose as a machine in which the power is generated, as in steam engines or internal combustion motors, but still there is a large territory that can readily be covered by vehicles of this kind. The number of electric light and power stations all through the eastern states, as well as those of the middle west, is so great that touring, at least beyond city and suburban limits, is one of its possibilities.

To offset the disadvantages of the electric automobile, due to

its limited radius of action, may be cited its simplicity of construction and operation. A light lever on one side serves to adjust the controller to any one of the three speeds for which the mechanism is adapted; the stearing gear is conveniently manipulated by one hand, and the brake is applied by the foot.

In order to give a clear idea of the method of wiring a battery for these speed changes, reference is made to the diagrams A, B and C of Fig. 6.

The battery is here supposed to consist of forty cells placed in four crates holding ten each, and marked 1, 2, 3, 4.

In A the cells in each crate are connected together in series; that is, the positive pole of one cell is connected to the negative pole of the next. The positive wire of each crate is connected to the positive side of the controller, from which a wire runs to the motor. The same is done with the negative wires, with the result that, when in the position A, the individual cells of each crate are connected in series, while the crates themselves are joined to the motors in parallel. This is for the lowest speed for the motor.

In the next position, B, of the controller the positive wires from 1 and 3 unite at the controller at 6, and thence run to the motor.

The negative wire from 1 runs to 7, where it meets the positive wire from 2, while the corresponding wires from 3 and 4 unite in 8. The negative wires from 2 and 4 run to the controller at 9, and thence to the motor. Under this arrangement the cells in the crates 1 and 2 and 3 and 4 are coupled in series respectively, while the two groups, 1, 2, and 3, 4, are in parallel. Under these conditions the voltage given to the motor is twice as much as under the A arrangement, and the vehicle will run at the second or intermediate speed.

In the final position, C, of the controller the whole set of crates 1, 2, 3 and 4 are coupled in series, and it will be seen that the positive wire from 1 leads through the controller directly to the motor 5. The negative wire from 1 leads, still through the controller, to the positive side of 2. In the same manner the negative wires from 2 and 3 are run to the positive sides of 3 and 4 respectively. Finally, the negative wire from 4 runs to the controller at 7, and thence to the motor.

In this way all of the crates are coupled in series and the highest voltage is delivered to the motor. This is twice as much as in the B arrangement, and gives the greatest speed to the vehicle. These combinations can be varied, but the principle of action remains unchanged. It is this simplicity of operation that is one of the strongest points in favor of the electric vehicle.

This is, of course, speaking merely from the viewpoint of general principles, as the discussion of the relative merits of individual motors, as made by different manufacturers, is quite impossible in this connection.

Other details closely allied with that of the motor itself are

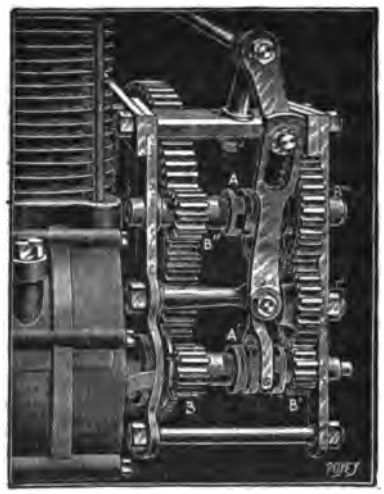


Fig. 7. Didier System of Change of Speed.

the methods employed for effecting a change of speed and for compensating for the difference in the distances traveled by the wheels on the two sides of a vehicle when traversing a curve.

The problem of changing speed has been a serious one, especially with gasoline and other internal combustion motors. The power of such a motor is well known to be proportional to the mean couple exerted by the piston upon the crank pin, and to the angular velocity of the motor. But in this type, contrary to what occurs with an electric motor, the mean couple is sensibly constant, and the power varies in inverse ratio to the angular velocity.

In order to obtain the best efficieney of a gasoline motor, the ratio of the speed of the vehicle to that of the motor should be changed without varying the latter, which should remain constant and retain its normal maximum value. This is an ideal that has not yet been attained in automobile carriages, but there are some approaches toward a solution. Meanwhile, manufacturers are content to adopt three or four different speeds for carriages, and but two for tricycles and phaëtons.

As an illustration of one of the methods that have been used to effect a change of speed, that known as the Didier is given in Fig. 7. The changes were made through substantial notched clutches with strong and sure notches. The arrangement shown in Fig. 7 consists of five gear wheels and a double clutch placed in a frame. The two pinions, BB″, mesh directly with the toothed wheel of the vehicle and remain always engaged therewith. The pinion B is mounted loosely upon its shaft, while the pinion B″ is fastened to its own shaft, and revolves with it. To the right of these two pinions there are three others, of which the smallest, B′, turning loosely upon its shaft, actuates the pinion B″, through the intermedium of the loose pinion C. Two clutches operated by a rocking lever permit of making the proper connections between these different parts and thus effecting the change of speed.

In order to change from high to low speed, it suffices to cause the two clutches to slide upon their axles. The upper clutch A then renders the pinion B″ and the upper axis interdependent, while the clutch A′ throws the pinion B into action, and thus turns the pinion B′. Motion to the axis of the differential gearing is then transmitted by the gear wheels B′, C and B″′. By changing the number of teeth in the pinions B′, C, B″′ and B″, it is possible, at will, to modify the ratio of reduction and sacrifice the speed upon the ascent of heavy grades, or in propelling weightier phaëtons.

While running at a high speed, the gear wheels B′, C and B″′ do not work. While the two clutches are in an intermediate position, everything is thrown out of gear and the motor can continue its operation without actuating the vehicle.

It is evident that this system could be extended by a combination of levers and additional gear wheels, whereby a greater number of speeds could be obtained.

Other speed changers have been introduced whereby a belt is carried from one wheel to another whose effective diameters it is possible to change; thus varying the ratio of revolution of their shafts.

Closely allied to the speed changer is the compensating gear.

When electric propulsion is used with two motors driving the wheel at opposite ends of the axle, no compensation is needed, but for gasoline and steam motors delivering power direct to the axle, then some form of compensating gear must be used in order to enable the vehicle to move in a curved line without a binding or slipping of the wheels.

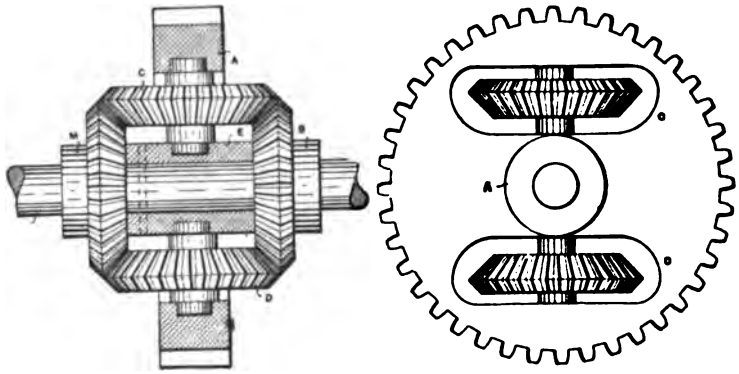
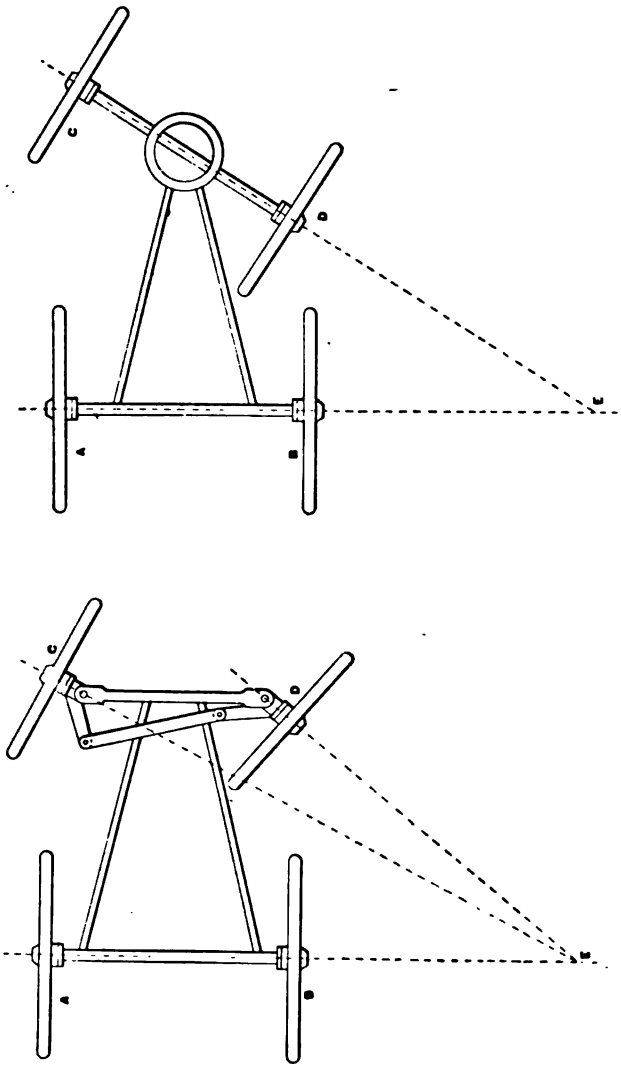


Fig. 8. Compensating Gear for Automobile Axles.

Fig. 8 shows a form of compensating gear that, with various modifications of detail, has received a very extensive application. The axle is divided at the center, and riding on the two abutting ends is the hub E of the gear or sproket A. This hub rides loosely upon the axle, and in the body of the gear are the two freely moving bevel pinions C and D. To the two ends of the shafts the bevel gears B and M are respectively keyed. It is evident that under ordinary conditions on a straight line the two bevel gears B and M will be rotated with their shafts in the same direction and at the same speed as the gear A. But when passing a curve it is quite possible for either of these gears to turn more slowly than the other and thus permit the desired compensation in the movement of the wheels.

The kind of tire to be selected for an automobile is important

since it has a decided influence on the amount of power required to propel the vehicle. The range of selection is, however, rather limited, in that it is confined to the iron, hard or solid rubber and the pneumatic. The matter was taken up in France in 1897, and



Figs. 9 & 10. Steering Gear for Automobiles.

some experiments were made on the amount of power required to haul the same vehicle at a speed of thirteen miles an hour when equipped successively with each of the three sorts of tires. It

was found in the first place, as would naturally be surmised, that the tractive stress was far more regular, and that the shocks were less with the pneumatic than with either of the other two. The tests were made over good macadam roads in all conditions, from dry and hard to wet and water-soaked, as well as over pavements in various conditions of repairs, and in all cases the average coefficient of traction of the pneumatic tire was less than that of the iron tire by about nineteen per cent, and the solid rubber tire by about fourteen per cent showing that there is a most decided advantage to be gained by the use of the pneumatic tire.

While the locomotive follows a definite predetermined course as defined by the rails, the automobile is dependent for its guidance upon a steering gear that is under the control of its driver. These gears vary widely in their methods of application, and run the whole gamut from the good through the indifferent to the bad. It will be beyond the scope of this article to enter into a discussion of all that has been done in this direction, but two fundamental principles will be shown as examples of current practice.

It is most important that the steering gear should give the driver complete control of the machine, be quick in its action and not likely to get out of order. The French machines are usually operated with a hand wheel and worm gear. This makes it possible for the operator to relax his grasp occasionally on the wheel, but possesses the disadvantage of being slow to operate, particularly on curves of short radius. The American machines, on the other hand, ordinarily use a lever for steering, which while quick in action compels the driver to keep his hand upon it at all times, for with a machine running fifteen miles an hour or twenty-two feet per second on a roadway twenty-five feet wide, a relaxation of vigilance and action for a period of one second would be quite sufficient to ditch the conveyance.

The fundamental idea of all steering gears is that, when on a curve, the center lines of the axle of each wheel should radiate from a single point, if side slipping is to be avoided. Thus, suppose in Fig. 9 the rear wheels A and B are on a fixed and rigid axle standing at right angles to the vehicle. Then, if the front wheels C and D are on short axles pivoted to the main axle, these

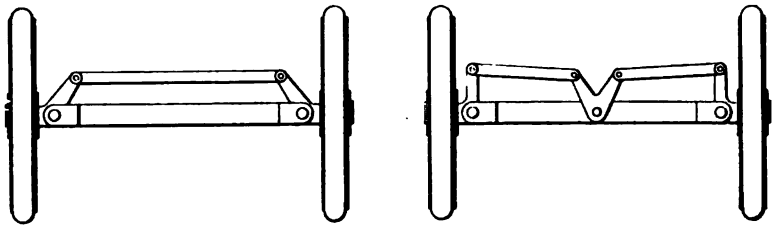
Modern Steam Automobile Fire Engine.

short parts must be turned so as to radiate from some point E in the line of the rear axle. The same holds true of a vehicle with the front wheels on a single axle that is itself pivoted at the center, as shown in Fig. 10.

Where the arrangement of Fig. 9 is used there must be an arrangement to vary the throw of the two wheels to meet the requirements of their respective radii. The amount of variation between them depends upon the length of the wheel base, and increases therewith.

An outline of the methods adopted is given in Figs. 11 and 12, which show the vehicle on a tangent, while in Fig. 9 is shown the position assumed by the gear of Fig. 11 on a curve.

One more detail and one only will be touched upon, and that



Figs. 11 & 12. Steering Gear for Automobiles.

is the brake. It is evident that with the use of pneumatic or even solid rubber tires the use of a shoe acting directly on the wheel will be entirely out of the question. The most satisfactory type of brake is, therefore, one in which there is a brake wheel attached to and revolving with the axle to which a brake band is applied for the purpose of obtaining the necessary resistance to the movement of the vehicle.

One such form, known as the Renault brake, is shown diagrammatically in Fig. 13. The band wheel A is attached to the axle and the two ends of the band B are connected to opposite ends of the equalizer C, which is moved so as to tighten the band when acted upon through a combination of levers, readily understood from the engraving, and worked by a foot pressure at D.

There are, of course, innumerable combinations of levers that will serve to accomplish the same result, but this serves to illustrate the general principle.

Having thus discussed the underlying features of automobile

work it now remains to describe a few of the many types of vehicles that are already upon the market. The growth of the industry has been so rapid, and the introduction of the automobile has been so successfully accomplished, that there is hardly a type of horse-drawn vehicle that has not its counterpart in one propelled by steam or gasoline engines or electric motors.

As it is evidently impossible within available limits to enter into an exhaustive description of all wheeled vehicles, a few typical examples will be chosen and illustrated, showing the more common types used for pleasure and commercial purposes.

Figs. 14 to 17 show the ordinary types of carriages propelled

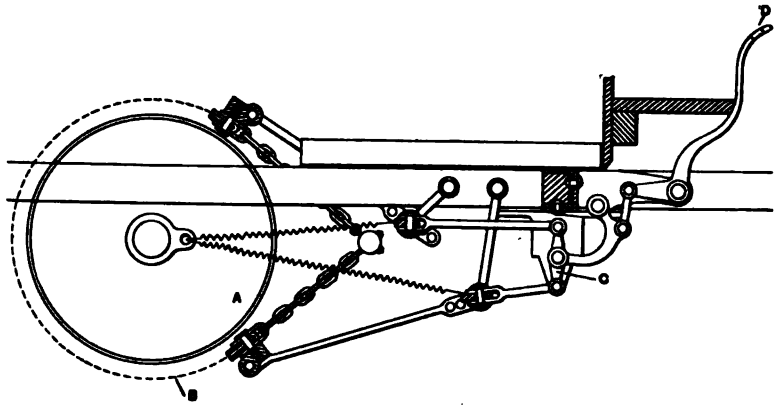


Fig. 13. The Renault Brake.

by steam and electricity. The gasoline motor carriages do not differ in essential particulars from these. It will be noticed that the steering gear for each of these is of the lever form, requiring the constant attention on the part of the operator already alluded to. A noticeable peculiarity of all of these carriages, when compared with the horse-drawn one, is the box or body that is necessarily provided for the accommodation of the working mechanism.

Fig. 18 is given as an example of the French type of construction. It will be noticed at once that the carriage has a heavier appearance than its American counterpart, and this is especially prominent in the greater weight of the wheels.

The motor is placed at the front, enclosed in a detachable casing provided with several doors, and is of the internal com-

bustion type using gasoline. The motor shaft carries a number of movable gear wheels which are of various diameters, and which when respectively thrown into engagement with one of an equal number of fixed gear wheels, drive the carriage at a speed varying with the diameter of the one in use at the time. The steering is accomplished by means of the inclined shaft and hand-wheel working a worm in

Fig. 14. Prescott Steam Carriage.

Fig. 15. Locomobile Steam Surrey.

Fig. 16. Victor Steam Runabout, 1902 Model.

accordance with accepted French practice, to which attention has already been called.

In addition to those here illustrated there is an innumerable variety of others serving practically the same purposes.

In the way of special work the self-propelled

steam fire engine was among the first to receive attention, but the great weight of the machine, coupled to its helplessness on

Fig. 17. The Columbia Electric Hotel Bus.

slippery or snow-covered streets, prevented its adoption.

Among the various attempts that have been made to increase

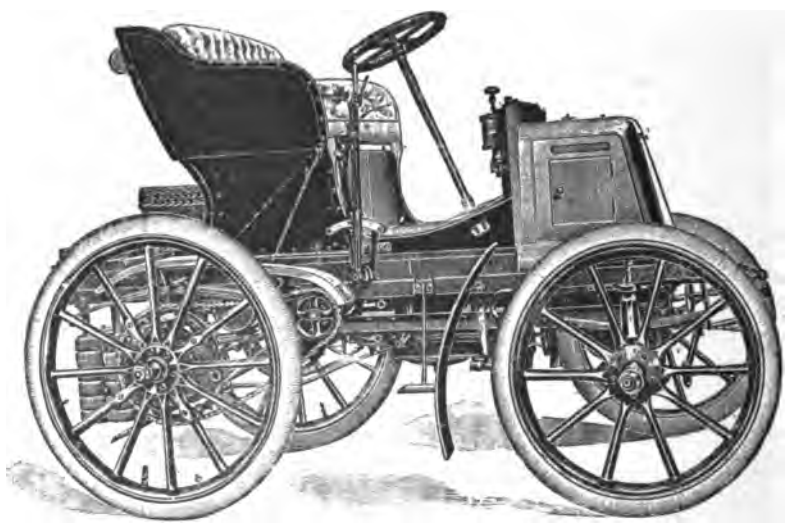


Fig. 18. Six Horse-power Panhard-Levassor Carriage.

the range of action of the electric vehicle, is one that was brought out in Berlin in 1900. It was applied to an omnibus seating

twelve passengers, and with a storage battery capacity for a run of from nine and one-half to eleven miles. In order to increase this small radius of action contact poles were placed upon the roof, by means of which the omnibus could not only be propelled by a current taken from the overhead city wires, but a recharging of the batteries could be carried on from the same source of supply at every available opportunity.

While the automobile is destined to an extended use in the form of pleasure vehicles, it is in the delivery wagon and trucks for heavy loads that its widest field of usefulness lies; just as the work horse is more valuable to the community, as a whole, than the carriage horse or racer.

The question of economy is one of prime importance in considering the adoption of the automobile especially for business purposes, for it is in this field that it is expected to develop its especial usefulness, and it is here that it has demonstrated its great value, proving beyond a doubt that it is far more economical in maintenance and operation than a horse. The first careful and critical comparative analysis of the factors entering into the cost of haulage by horse and automobile was made in 1899 in connection with the delivery service of one of the large department stores in New York City.

It was learned in the course of this examination that the average mileage for a horse was about fifteen daily, and that the cost was about two and one-half cents per mile more than with an electric delivery wagon in the same service.

These figures were only reached after months of careful study, but they have since been more than corroborated by the great advances that have been made in the introduction of the automobile for commercial purposes.

A good example of a truck for heavy traffic is shown in Fig. 19, designed for the Adams Express Company. A vertical fire tube boiler is used having about seventy square feet of heating surface. The wheels are straight and of substantial construction, the front ones being four feet and the rear ones four feet six inches in diameter.

The engine has been designed to develop twenty-five horsepower at a normal speed of four hundred revolutions per minute.

It is of the compound type, and enclosed so as to use splash lubrication.

The platform has a clear loading space of twelve feet by four feet seven inches. The height of the same is four feet four inches, with a slight slant downwards towards the rear of the wagon. The wheels are set to track five feet six inches. This vehicle is designed to take the full load of five tons up the steepest hill which it is liable to encounter, and has two speeds, three and seven miles per hour, respectively.

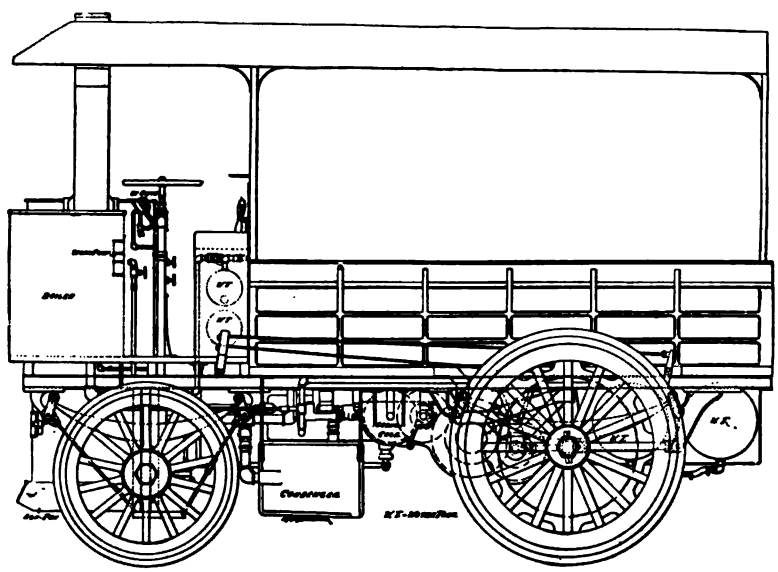


Fig. 19. Elevation of Steam Express Wagon of the Adams Express Company.

The value of the automobile is not confined to carriages and trucks, but there seems to be a wide field open for it in the line of self-propelled farm machinery as soon as farmers realize that they can do the work as efficiently as with horses, and at a less expense with hydrocarbon motors. Already a number of experiments have been made in this direction, which have resulted in the development of several examples of auto farm machinery. Among the simplest of these is a mowing machine of light and compact design.

This machine has been operated under all of the conditions

of actual service, but it has not yet been placed upon the market, because the builders believe that its cost of manufacture makes it too expensive for the farmer at present. So long as he is obliged to keep horses for his other work he will prefer to cut grass and grain with simple machines drawn by them, rather than make the large additional investments that would be called for if he wished to use motors.

In one respect, however, this machine seems to be superior to the ordinary mower drawn by animals. It is a three-wheeled machine, with two driving wheels like those of an ordinary mower, and a third or steering wheel placed in front. This steering wheel is located at one side, where it runs in the path cleared by the swath board. As none of the wheels run over the swath the grass is not pressed down as it is when horses draw the machine. When ordinary mowers are used the grass is trampled down, so that it is generally necessary to go over it with a hay tedder and shake it up before it will cure.

There are difficulties, however, in the way of using motors for driving agricultural machines which are not likely to be surmounted by the means available in the present state of the art. Nearly all agricultural work involves driving with a machine or implement over soft ground, and the weight of the engine necessary to propel such machines and implements, when added to the ordinary weight of the operative parts, would make the traction wheels sink into the ground so deep that the power required would be greatly increased. Traction engines are generally used by thresher men to draw their outfits from one farm to another over the roads, which are usually dry and hard during the threshing season, but these engines have never been used in the field to any extent. Besides the constant waste of power in climbing through soft ground, the soil under such conditions will give way or roll backward under the traction wheels, and there is an enormous additional waste of power on this account. While threshing machine engines are now built all the way from fifteen to thirty horse-power, and weigh no more than would be necessary to hold the wheels down in pulling with this amount of power, these engines have never been used successfully in the field, except in a few instances, for fall plowing when the ground is hard.

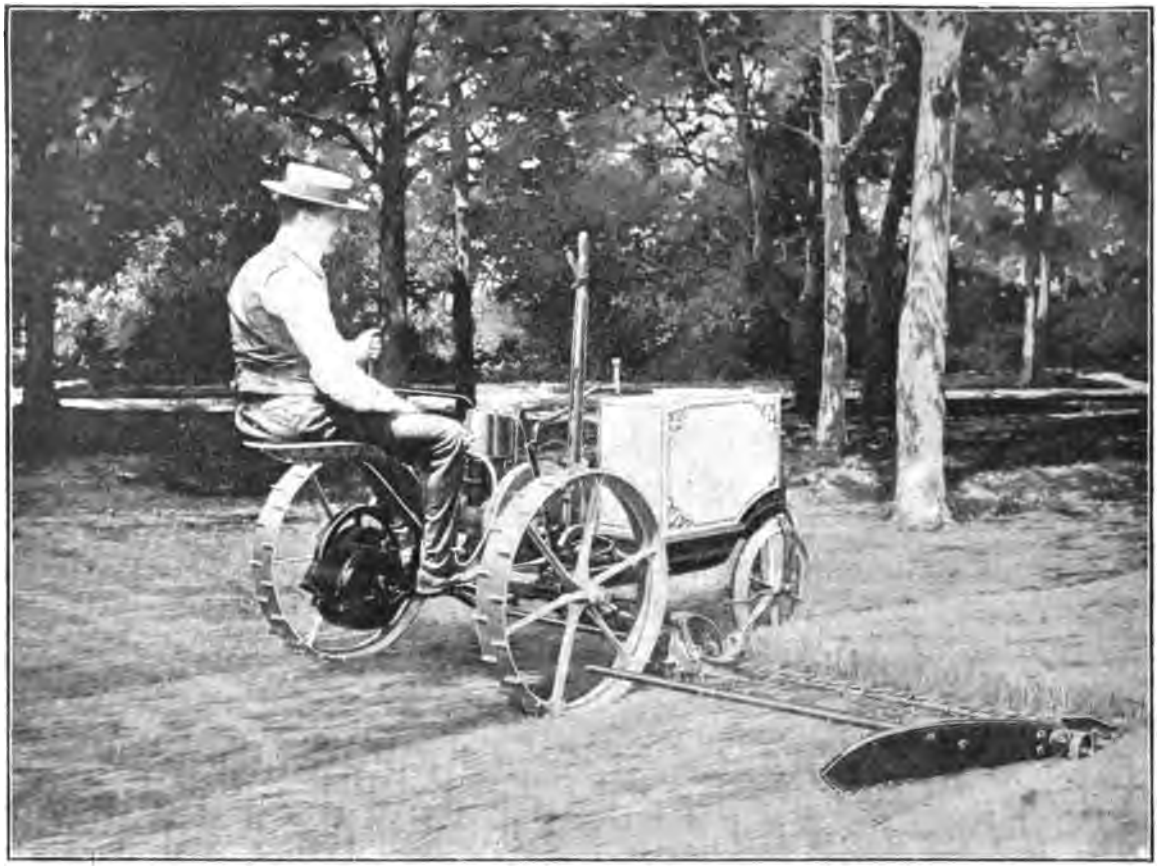
Mechanical traction has, nevertheless, been successfully applied to agricultural work to a limited extent. Its first application for this purpose was made in plowing by steam, but this was not true automobilism, since the plows were hauled by a cable worked by an engine at rest. There were many evident objections to this plan, and it never received an extensive adoption. Since the automobile for road purposes has been so extensively developed, however, a number of traction engines have been designed for the especial purpose of hauling agricultural machinery, such as plows, harrows, cultivators, and the like, but all are open to the objections enumerated above.

Naturally no method of transportation could have attained the importance acquired by the automobile without attracting the attention of military experts who are always on the *qui vive* to increase the efficiency and mobility of their forces. So, while the automobile has never been used in actual operations in the field, with the exception of a slight extent in the recent Boer war in South Africa, considerable attention has been paid to its development for military purposes. The French army, in particular, has been equipped with a varied assortment of these vehicles, which have been used with more or less success in the annual manœuvres. They are divided into three classes:

1. Automobiles for the transportation of the personnel.
2. For the transportation of special material.
3. Traction engines for the transportation of heavy guns and stores.

Of the first there are a number of carriages whose speeds range from eighteen to thirty-six miles an hour, and whose accommodations vary with the rank of the officer for whose uses they are intended. The second includes special mail, telegraph supply, telegraph operator's, surgeon's wagon, ambulances and the like, while the last includes heavy traction engines that are driven by steam.

Of all of these automobiles the traction engines gave the most promise of future success. Despite their cost they are less expensive than the horse, for which they are substituted, and the repairs which must inevitably be made are by no means equal to the loss of draft animals during a war. The coal or coke consumed as fuel



An Automobile Mowing Machine (Steam Propelled), Made by the McCormick Harvesting Machine Company.

can be obtained for one-quarter the cost of fodder and occupies but one-twentieth of the space.

The standpoint of the French officers is that in actual warfare it is a matter of no little difficulty to procure fodder, whereas coal, on the other hand, is found almost everywhere — a position, however, upon which there might well be a difference of opinion.

The same plea for economy of space holds here as in a city street, for the train of an army corps is reduced from fourteen to six miles in length if traction engines alone are employed. The normal speed of draft animals is from two and one-half to four miles, with a maximum speed of from four to five miles an hour, a day's journey rarely exceeding sixteen miles. With traction engines, on the contrary, the normal speed attainable is from four and one half to five miles, while, in an emergency, from seven and one-half to eleven miles can be covered in an hour. Then, since the machine never becomes tired, no limit can be set on the distances which can be traversed.

Such is the position taken by the advocates of the automobile for military work; but whether its performance in actual warfare will fulfill these expectations is a matter for the future to decide.

It goes without saying, of course, that, with the construction of vehicles intended to take the place of ordinary carriages and trucks, there must have been many elaborations, some of which went beyond the bounds of practical utility. An instance of this is to be found in a vehicle designed in France in 1898. It was thirty-eight feet long over all, and was arranged with a kitchen in the rear with sleeping accommodations for two servants; a second compartment in the middle contained bath and toilet conveniences, while at the front there was a large saloon serving as a dining and sleeping compartment.

Though such vehicles may be occasionally built they will hardly figure largely in the automobile industry taken as a whole, and must be regarded as belonging to the class known as "Special," if the term of obloquy, "Freaks," is not applied to them.

We now come to the last and, to the world, least profitable class of automobiles, the racing machines. It was this type of vehicle that was first brought into prominence, and its development has been rapid in the extreme. Speeds rivaling that of

express trains have been repeatedly attained, and the endurance of the mechanism, when subjected to the great stresses of racing over country roads, has far exceeded that supposed possible when the work was begun.

France is essentially the home of the racing automobile, and long-distance runs at high speeds have been made common occurrences by their frequent repetition over a long interval of time. They began at a period when the automobile was an unusual sight, and continued without interruption for a number of years.

As an example of this kind of sport the great automobile race known as the Tour de France may be cited. It was organized in 1899 by one of the great daily papers of Paris, under the auspices of the Automobile Club. The course started and ended at Paris, and included on the route Naucy, Aix les Bains, Vichy, Perígueux, Nantes and Cobourg. The distance was 1,330 miles, and was divided into seven stages, to be covered in nine days. The race was won in an actual running time of 44 hours and 44 minutes.

This is a characteristic example showing how automobile racing has naturally come in with the use of such vehicles for pleasure purposes.

Other runs that have been made are from Paris to Bordeaux and from Paris to Berlin. A race between the two latter points was one of the features of the summer of 1901. The distance was 742 miles, was divided into three stages, and the actual elapsed time of the winner was 17 hours, 3 minutes and 43 seconds, making an average speed of about 43½ miles an hour for the whole distance. It cannot be said, however, that the sport is popular with the great mass of inhabitants, while it is simply detested by the peasants.

The following are a few record speeds that have been made in various automobile races:

AUTOMOBILE RECORDS.

Distance	Time	Date	Place	Make of Vehicle	Kind of Motor	Conditions
*1 mile.	51.8 sec.	Nov. 16, 1901	Brooklyn, N. Y.	Mors	Gasoline	Road
1 "	1 min. 12.0 "	May 31, 1901	Staten Island, N. Y.	Locomobile	Steam	Race Track
1 "	1 " 3.0 "	Nov. 16, 1901	Brooklyn, N. Y.	Riker	Electric	Road
1 "	1 " 9.6 "		Nice, Italy.	Mercedes	Gasoline	Road
1 "	1 " 27.6 "	Nov. 16, 1901	Brooklyn, N. Y.	De Dion	Gasoline	Road
2 "	2 " 13.8 "	Oct. 24, 1901	Detroit, Mich.	Winton	Gasoline	Race Track
3 "	3 " 20.2 "	Oct. 24, 1901	Detroit, Mich.	Winton	Gasoline	Race Track
4 "	4 " 27.2 "	Oct. 24, 1901	Detroit, Mich.	Winton	Gasoline	Race Track
5 "	5 " 33.8 "	Oct. 24, 1901	Detroit, Mich.	Winton	Gasoline	Race Track
10 "	11 " 9.0 "	Oct. 24, 1901	Detroit, Mich.	Winton	Gasoline	Race Track
15 "	19 " 10.8 "	Sept. 26, 1901	Fort Erie, Canada.	Mors	Gasoline	Race Track
20 "	25 " 25.4 "	Sept. 26, 1901	Fort Erie, Canada.	Mors	Gasoline	Race Track
25 "	31 " 44.2 "	Sept. 26, 1901	Fort Erie, Canada.	Mors	Gasoline	Race Track
50 "	1 hr. 17 " 50 "	Sept. 18, 1900	Chicago, Ill.	Winton	Gasoline	Race Track
100 "	2 " 30 " 1 "	April 14, 19 0	Long Island, N. Y.	Gasmobile	Gasoline	Road
700 "	38 " 30 " 0 "	Nov. 1-4, 1900	Cleveland, O to N. Y.	Winton	Gasoline	Road

*World's record, Sept. 1, 1902.

Closely allied to this matter of long-distance racing at high speeds comes in that of the speed regulation of automobiles on the highways. This is one of the most difficult problems with which the police of large cities have to deal. In case of an arrest it is difficult to come to an agreement as to whether a carriage was running at a speed of eight or eighteen miles an hour, or simply at too high a speed.

There is nothing but an automatic registration that will give satisfaction to everybody, and so different methods have been proposed. One of the most ingenious suggestions is that of a French manufacturer of photographic apparatus. It is that a shutter with two openings be used upon a camera with a comparatively slow plate. The interval between exposures due to the two openings can be accurately timed, so that a simple measurement of the displacement of the images on the plate will give the velocity of the carriage at the time of the exposures. Such a record would be valuable and convincing.

It appears, however, to be the settled policy of magistrates before whom cases of excess speed are brought to impose the maximum penalty in the case of a fine, so as to make speeding such an expensive luxury that the tendency of even the most reckless will be to keep within the prescribed limits of the law.

At the same time the rights of the motor vehicle to the use

of the common thoroughfares has been fully conceded, not only by the public but by the courts, before whom the question has been brought.

As the question depends not upon the construction of the statutes, but upon the application of the principles of common law, the justices' analysis of a case brought in a New Jersey court applies with equal force in all states.

The prosecution having made the contention that the motor vehicle was a nuisance, and had no rights upon a public highway, the justice charged as follows:

"The question is whether the machine driving along the country roads without a horse in front, and discharging steam behind, is so likely to frighten a horse on the highway and thus endanger the road as to constitute the machine a nuisance. It is argued that it is an improved method of locomotion, but it does not follow that it is to be tolerated. The right to drive horses along the highway is an established right, a common right, and if a modern method of locomotion is used of such a nature that it commonly brings discomfort and danger to those exercising the common right, the established right to travel on highway, then it it is a nuisance, and cannot be tolerated. But it does not follow it is a nuisance because it occasionally or exceptionally frightens horses. That would not make it a nuisance. In order to make it a nuisance its common effect must be to substantially interfere with the people who drive horses along the highways. Is it of such a nature that it is so likely to frighten horses and thus endanger travelers on the highway as to make it a nuisance, or is it only its exceptional effect? If it is its common effect, then it is a nuisance; if it is an exceptional effect, it is not a nuisance. If this method of locomotion is a common nuisance, and was the approximate cause of death, then the defendant is responsible."

It is evident from this charge that, if taken as a precedent, the motor vehicle will be considered as having a right to traverse the public highway, a right which has already been conceded to it by the community at large.

But this right cannot be construed to a right to run at speeds that are unsafe for any vehicle not provided with a track especially constructed for its use.

We finally come to the all-important point of the selection of an automobile suited for any especial purpose. Take that of the selection of one for a pleasure carriage as an example. It should be made with a great deal of care if any approach to perfect satisfaction is to be expected. With all due respect to the builders of these machines, it is but natural that each should represent his own as being the best and most desirable from every point of view. It is, therefore, a little unsafe for the novice to trust implicitly to the interested parties in coming to a decision.

Of course the object for which the machine is to be purchased must receive the first consideration. If it is to be a racing vehicle, many things must be sacrificed which would otherwise be considered indispensable, but as these are in the minority they may be passed by, and a few suggestions made for the man who wishes a carriage capable of making from twelve to fifteen miles an hour over fair country roads. In choosing such a vehicle it must be remembered that it is subjected to wear and tear, and that repairs both temporary and permanent will be required. In order that these may be maintained with a minimum of expense, all of the working parts should be readily accessible. It is a good rule, though one difficult to meet, that any part should be capable of removal and replacement without disturbing any of the others. To determine just how near this can be done, it is well to inspect with a view to repairing each and every part.

Then strength should come in. To sacrifice this to lightness and daintiness of design is poor economy. The machine should be capable of doing rough work in inexperienced hands without danger of breaking down, and of developing power enough to surmount hills without coaxing or stalling. In case the purchaser does not feel competent to decide upon these things, an expert and disinterested outsider should be engaged to report and recommend.

As for the operator, more should be done in the way of preparation than merely learning the motions of stopping and starting supplemented by a little perfunctory information regarding the most apparent features of the mechanism. The machinery should be studied in detail by means of drawings, and dismantled

parts, until thorough familiarity is acquired with the functions and operation of each individual piece. It is only by such a thorough knowledge of all parts of the mechanism that the owner can feel assured that, come what may, he will be capable of caring for his machine in the best and most economical manner.

This matter of design is a most serious one to the would-be purchaser, for it is a lamentable fact that much of the trouble experienced with automobiles and electric vehicles particularly, has been due to the haphazard or disconnected work of designing. Many bear the evident mark of having been done by a number of different persons. The vehicle proper has been designed by the builder who has usually purchased the motor from another, who in turn guaranteed that it would render a certain definite service under certain definite conditions that were more than apt to be exceeded on badly paved streets or uneven country roads. And finally the manufacturer of the battery was asked for something to go in a fixed space, and was given scant information as to the actual service to be rendered. Under such conditions it is not strange that the early electric automobiles were not as satisfactory as might have been desired. These conditions were, however, changed with the experience gained from service and the proper relations between the various elements established.

The same statement holds true with equal force in regard to many other types that have attracted more or less attention.

In this brief review of the conditions of automobilism it has, of course, been impossible to do more than touch in the most cursory manner upon any one of the manifold features of this many-sided and rapidly developing industry. In fact so rapid is the progress made along the whole line of automobile construction that what may be fresh and new at the time of writing is apt to be obsolete and of the past by the time it has been put upon a printed page. That there is a wide and ever widening field for this class of vehicle there can be no doubt. At first adapted to and used upon the good roads near the large centers of population it will enlarge its radius of action and influence, an influence always tending to the betterment of the highways; and, as these latter are improved, its own apparent value will be increased, so

that the two will react upon each other; tending to a constant improvement of the one, and a more and more extended application of the other.

Under such conditions it seems as though the automobile promised to be one of the most potent factors that the world has ever seen in the development of the transportation facilities of every country into which it is introduced.

APPENDIX

QUESTIONS IN REVIEW

The following lists of questions afford the reader a means of testing his knowledge of the subjects treated in the present volume. Any one who has carefully read the foregoing subjects should be able to answer every question accurately. The reader is advised to go through the questions thoroughly, working out his answers and checking his results with the answers given. This will afford a valuable means of fixing the matter in mind. Students who are preparing for examinations for college, civil service or engineer's license will find the questions of the greatest value.

REVIEW QUESTIONS

ON THE SUBJECT OF

CHEMISTRY.

---

1. What is an atom?
2. Name six common elements.
3. How many molecules in the following, and how many atoms of each element? $3\ CaCl_2$, $4\ Fe_2\ (SO_4)_3$, $6\ NaOH$.
4. What is specific gravity?
5. What is atomic weight?
6. A certain coal contains 78 per cent carbon and 6 per cent hydrogen. How many B. T. U. will be produced in burning one pound? Ans. 15,030 B. T. U.
7. How many pounds of water at 62° F. will be evaporated into steam at atmospheric pressure per pound of the coal mentioned in Question 6? Ans. 13.46 pounds.
8. State the law of conservation of matter.
9. What is the molecular weight of common salt (NaCl)? of calcium chloride ($CaCl_2$)?
10. How many pounds of air are theoretically necessary to completely burn 200 pounds of coal that contains 82 per cent of carbon and 8 per cent of hydrogen? Ans. 2,459 pounds.
11. Write the equation for the action of sulphuric acid on zinc.
12. Explain the calcium light.
13. What is an element?
14. What is the atomic weight of oxygen, hydrogen, C, iron and Cl?
15. What is the difference between a chemical compound and a mechanical mixture?
16. What is a saturated solution?

17. What is the valence of the metals in the following, CuO, K_2O, and AgCl.

18. What is argon?

19. Explain "dew-point."

20. What is combustion?

21. How is water-gas made?

22. Is air a chemical compound or a mechanical mixture?

23. Explain distillation.

24. Give the symbols for carbon, phosphorus, sulphur, iron, lead, tin, zinc, oxygen and copper.

25. What is a molecule?

26. Explain with reactions the combustion of coal in a stove.

27. State some of the uses of graphite.

28. Of what elements are hydrocarbons composed? Are hydrocarbons more or less volatile than carbon?

29. Express 2 atoms of hydrogen, 6 atoms of zinc, 3 atoms of nitrogen, 4 molecules of water, 5 molecules of carbon dioxide, and 7 molecules of sulphuric acid.

30. Describe briefly carbon dioxide and carbon monoxide and state their chief differences.

31. Describe briefly the three states in which carbon is found.

32. What is valence? What is the valence of potassium knowing that potassium chloride is KCl?

33. Name some of the most important compounds of hydrogen with the elements oxygen, carbon, sulphur and nitrogen.

34. Of what elements is sugar composed?

35. State briefly the properties and characteristics of oxygen.

36. Name the most important gases found in the atmosphere.

37. What are the products of combustion when coal is burned in plenty of air?

38. Why is it more desirable to burn carbon to CO_2 than to CO?

39. How many pounds of oxygen unite with one pound of hydrogen to form water?

40. A coal contains 73 per cent. carbon and 4 per cent. hydrogen. Find the heat of combustion per pound.

REVIEW QUESTIONS

ON THE SUBJECT OF

METALLURGY.

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1. What is blister steel? How is it made?
2. What takes place when cast iron is made into wrought iron? Name the principal process.
3. Name three ores of iron with their approximate percentages of iron.
4. Why is the percentage of silicon important in iron castings?
5. What are the advantages of the Bessemer process of making steel? Of the Open Hearth process?
6. Explain the process for reducing iron ore to metallic iron. Give reaction.
7. What is the advantage of heating the blast of the blast furnace?
8. By what method is wrought iron made directly from the ore?
9. Give some of the qualities of pig iron. What chemical elements does it usually contain?
10. Why has mild steel replaced wrought iron? Why is wrought iron more easily welded than mild steel?
11. What is flux? What is slag?
12. Why does pig iron make good castings?
13. What is spiegel? State its use and approximate composition.
14. Describe briefly the Bessemer converter.

15. Of what is the lining made in the "acid" Bessemer converter?

16. Describe briefly the process of tempering. What color denotes the hardest temper?

17. What is the influence of manganese on pig iron? On steel?

18. Why is steel made in the crucible superior to both Bessemer and Open Hearth steels?

19. How is the melter able to judge when the Bessemer converter charge is ready to pour?

20. State some of the qualities of nickel steel. How is it "face hardened" in making armor plate?

21. What fuel is used in the Open Hearth process? Why?

22. What are Siemens regenerative chambers?

23. How is carbon expelled in the Open Hearth process? Write and explain the chemical reaction.

24. Describe briefly the blast furnace.

25. What is self hardening steel?

26. What fuel is used in the blast furnace?

27. What is the most important ore of lead? Of copper? Of tin? Of zinc?

28. What is a copper matte?

29. A piece of boiler plate (mild steel) is $\frac{1}{8}$ inch thick, 2 feet wide and 8 feet long. How much does it weigh?

30. Find the weight of zinc in 48 cubic inches of brass.

31. What is the principal use of copper? Of tin? Of zinc?

32. What is the shape of a lead blast furnace?

33. How is zinc produced?

34. How is galvanized iron made?

35. What are alloys? What is the composition of Muntz metal?

36. How is aluminum obtained? How does its electrical conductivity compare with that of copper?

37. What is the advantage of the electrolytic process of refining crude copper?

38. On what properties does the Park's process of desilverizing lead depend?

REVIEW QUESTIONS

ON THE SUBJECT OF

THE STEAM ENGINE.

PART I.

1. What should be the rim weight of a cast iron fly-wheel which is 15 feet in diameter, if the engine is of the Corliss type, with an 18″ × 36″ cylinder, and runs at 90 revolutions per minute?

2. In what way does the action of steam in the turbine engine differ from the action of steam in the ordinary reciprocating engine?

3. What is the theoretical height of a simple pendulum governor which makes 65 revolutions per minute?

4. In what way did Newcomen improve the steam engine?

5. Explain the difference between the condensing and the noncondensing engine, and show why the condenser increases the power of the engine.

6. Describe two methods of overcoming the danger due to high rotative speed in the steam turbine.

7. What two principles did James Watt follow in his experiments on the steam engine?

8. What types of engines have no fly-wheel? Why have they no fly-wheel?

9. What should be the thickness of rim for a cast iron fly-wheel weighing 4,480 pounds; the face is 12 inches wide, and the diameter of the wheel 15 feet?

10. Name some of Watt's inventions and improvements in the steam engine.

11. What is meant by compound and triple expansion engines?

12. What is a Woolf engine? What is a tandem engine? A cross compound?

13. Explain with sketch the action of a sight-feed cylinder lubricator.

14. What is the function of a governor?

15. Why is not the power given out by an engine constant during a given time?

16. What are the relative advantages and disadvantages of turbine engines as compared with reciprocating engines?

17. What is the office of the fly-wheel?

18. How does the height of the governor affect its sensitiveness?

19. Why are lubricants used? Name the requisites of good lubricants.

20. Name the advantages of the vertical engine.

21. Describe the two kinds of governors.

22. In what two ways do governors vary the work done on the piston?

23. How are high-speed engines oiled?

24. Which class of engine needs the larger fly-wheel, and why, high speed or low speed?

25. Describe the direct-acting steam pump.

26. How does the action of the Buckeye engine governor in changing the amount of steam admitted per stroke differ from the action of the straight-line engine governor?

27. What are the advantages and the principal disadvantages of the Corliss engine?

28. Name the requisites for high-speed reciprocating engines.

29. Why do pumping engines usually have devices for economy?

30. Explain how the expansion of steam is obtained in each of the two types of steam turbine.

31. If the height of a simple pendulum governor is 8 inches, what is the equivalent height if a weight equal to $1\frac{1}{2}$ times the weight of the balls is added?

REVIEW QUESTIONS

ON THE SUBJECT OF

STEAM ENGINE INDICATORS.

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1. A Brumbo Pulley has the following dimensions: lever 80 inches long, stroke 32 inches and radius of sector 10 inches. What will be the length of the diagram?

2. Define Mean Effective Pressure.

3. When is a three-way cock used?

4. Describe Watt's Indicator.

5. A steam engine has a stroke of 30 inches, diameter of piston 18 inches, and the initial pressure 110 pounds (gage). If steam is admitted during the whole stroke and the exhaust is at atmospheric pressure, what is the theoretical M. E. P.?

6. In the above engine, what is the theoretical indicated horse-power if the engine is running at 75 revolutions per minute?

Ans. 318 I. H. P.

7. Why is a reducing motion necessary in taking indicator cards?

8. After taking an indicator card, how is the atmospheric line drawn?

9. Give the formula for finding the Indicated Horse-power, explain the meaning of the letters, and why is the denominator 33,000?

10. What is a good height and length for an indicator card? What data should be placed on the diagram?

11. Describe the process of taking a card.

12. Explain with sketch the method of finding the area of an indicator card by means of ordinates.

13. If you were told to find the I. H. P. of an engine what data would you require?

14. What peculiarity has the Tabor indicator?

15. What will be the fault with the card if the spring used in an indicator is too light? If too heavy?

16. If the I. H. P. is 85.6 and the efficiency 90 per cent, what is the available horse-power?

17. If the initial pressure of steam is 85 pounds absolute and the exhaust pressure 2 pounds above the vacuum, what is the thermal efficiency?

18. An indicator card gives a steam consumption of 28.6 pounds per I. H. P. per hour. If the mechanical efficiency is 87 per cent, what is the steam consumption per B. H. P.?

Ans. 32.87 pounds.

19. A rope brake is attached to the fly wheel of an engine. The pulley is 36 inches in diameter and the rope 1 inch. If the spring balance registers 220 pounds and the weight is 20 pounds, what is the B. H. P. while the engine is running 300 revolutions per minute? Ans. 17.6 B. H. P.

20. Are the cards most reliable when taken by two indicators or when both are taken on the same paper by the same indicator?

21. What is the speed of an engine if the B. H. P. is 2.84, the length of arm of Prony brake 3 feet, and the weight at the end of the arm 35 pounds? Ans. 142 revolutions.

22. If the admission line of an indicator diagram curves backward, what does it indicate? How would you remedy it?

23. What is wire-drawing? Explain why it is undesirable.

24. The piston of an engine is 19 inches in diameter; the piston speed is 480 feet per minute. A card was taken with a 40-pound spring; the mean ordinate being 1.16 inches. What was the I. H. P.? Ans. 191.4 I. H. P.

25. What causes wavy lines in an indicator diagram?

26. What is the indicated horse-power of an engine $12'' \times 18''$ when running at 90 revolutions, the M. E. P. being 42 pounds?

27. An engine is $11\frac{3}{4} \times 15$. The piston rod is $1\frac{3}{4}$ inches in diameter. While running at 324 revolutions per minute cards were taken. The area of the head end card was 3.27 square inches; that of the crank end was 3.12 square inches. The cards were $2.87\frac{1}{2}$ inches long and a 48 pound spring was used. What was the total horse-power? Which end was doing the most work and how much more?

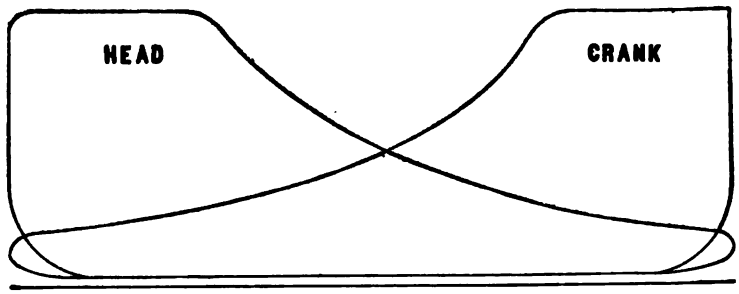
Ans. { 140.4 I. H. P.
Head end 4.86 I. H. P.

28. The ratio of the volumes of the cylinder of a triple expansion engine is 1 : 3 : 8. The M. E. P. from the diagram of the high pressure is 98 pounds, from the intermediate 41, and from the low is 14 pounds. The area of the low pressure cylinder is 2827.43 square inches, and the length of stroke 36 inches. What is the I. H. P. while running at 115 revolutions?

Ans. 2460 I. H. P.

29. The following pair of cards were taken from a 20×42 Fishkill Corliss Engine while running at 75 revolutions per minute. A 60-pound spring was used. Assuming the piston rod to be $2\frac{1}{4}$ inches in diameter what is the I. H. P.?

Ans. 230 I. H. P. (about).



30. Why is it more desirable to know the B. H. P. than the I. H. P.?

31. The area of the head end of a card is 3.02 inches, that of the crank end is 2.98 inches; if the length of the cards is 3.25 inches and a 50-pound spring was used, what is the average M. E. P.?

32. A locomotive with $19'' \times 24''$ cylinders and 72-inch

drivers is running at 50 miles per hour. It has an average load and the M. E. P. is 54.2 pounds, what is the I. H. P.?

Ans. 870 I. H. P.

33. Describe the method of combining the indicator cards of a triple expansion engine.

34. If a theoretical indicator card is drawn for a large single cylinder engine and the M. E. P. found to be 56 pounds, about what could be expected for the actual M. E. P.?

35. An engine runs 400 revolutions per minute. It is $10'' \times 15''$ and has a M. E. P. of 43 pounds. What is the mechanical efficiency if the rope brake test gives a B. H. P. of 94.15?

Ans. 92 per cent efficiency.

36. Show that there is considerable gain by using steam expansively in the cylinder of a steam engine.

37. Why is the calculated thermal efficiency never realized?

38. How is the pencil of an indicator prevented from pressing too hard against the paper?

39. The piston of a steam engine is 12 inches in diameter the length of stroke 18 inches, and the I. H. P. while running 92 revolutions is 42. At how many revolutions must the engine run to develop 52.5 I. H. P.?

Ans. 115 revolutions per minute.

NOTE: This problem may be solved by simple proportion, as the horsepower is proportional to the speed.

40. The pulley to which a rope brake is attached is 32 inches in radius. The rope used is $\frac{3}{4}$ inch in diameter. What is the B. H. P. if the spring balance registers 15 pounds, the weight is 65 pounds and the speed 132 revolutions?

Ans. 3.39 B. H. P.

REVIEW QUESTIONS

ON THE SUBJECT OF

VALVE GEARS.

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1. Why cannot the displacement of the piston be found in the same manner as that of the valve?

2. What is the throw of the eccentric if the valve travel is 3 inches and the rocker arm has the following dimensions: A B = 12 inches, A G = 15 inches?

3. If the outside lap is increased, what effect does it have on the steam distribution?

4. What is meant by lead?

5. Why is the Stephenson link preferable to the Gooch for locomotive engines?

6. Explain why the eccentric radius is not at right angles to the crank.

7. Why are laps used?

8. Can a stationary engine be vertical and double acting and at the same time condensing?

9. Describe an eccentric.

10. What is the simplest kind of valve?

11. When is the plain slide valve in mid-position?

12. Explain the action of a valve without lap.

13. Why is the outside lap called the steam lap?

14. Sketch a plain slide valve and indicate ports, bridges, exhaust cavity, inside and outside lap.

15. Give the advantages of the Corliss valve gear.

16. If the angular advance is increased what is the effect on the steam distribution of the plain slide valve?

17. With a connecting rod of ordinary length, explain why there is unequal steam distribution, if the valve is set for one end and if the laps are equal.

18. Is an eccentric used with the Joy valve gear?

19. If the outside lap is reduced how is the lead effected?

20. What is the most common type of link motion?

21. Referring to Fig. 16, will the line R O be perpendicular to X Y when the piston is in the middle of the stroke?

22. What should be the diameter of the steam pipe for an 18″ × 24″ engine that makes 100 revolutions per minute?

Ans. 5 inches.

23. If the inside lap is increased is cut-off earlier?

24. Describe the process of putting an engine on center.

25. How is the area of steam ports determined?

26. How are Corliss valves set?

27. When setting the Meyer valves, is the main valve given a late or early cut-off? Why?

28. What relation between cut-off and compression can be obtained with the Meyer valve that is impossible with the ordinary slide valve?

29. Does the cut-off valve of the Meyer valve effect the exhaust?

30. Describe with sketch the Stephenson link.

31. If the valve travel is increased how is the cut-off by an ordinary slide valve altered?

32. Explain why an engine runs in the opposite direction if the valve is disconnected from one eccentric and connected to another exactly opposite to the first.

33. What is the effect on compression caused by decreasing the outside lap?

84. How do the short ports of the Corliss cylinder cause a saving in steam?

85. What should be the width of the exhaust port?

86. How is a valve set with equal lead?

87. What is the advantage of the piston valve?

88. What are the advantages of the Joy valve gear?

89. What is one disadvantage of the Corliss gear?

40. How do the ports for the piston valve differ from those of the plain slide valve?

41. Describe two methods for balancing valves.

42. Is more power required to move a piston valve than to move a slide valve?

43. How does the Gooch link differ from the Stephenson link?

44. How is the plain slide valve set for equal cut-off?

45. What are "crossed rods"? How is the steam distribution different with crossed rods?

46. Why was the Allen link a success?

47. How does the passage in the trick valve effect lead? How does it effect admission?

48. For what two reasons are link motions used on locomotives?

49. Why are Corliss valves cylindrical?

50. How does the bringing of the block nearer the center of the Stephenson link cause cut-off to occur earlier?

51. Describe the double ported slide valve.

REVIEW QUESTIONS

ON THE SUBJECT OF

THE STEAM ENGINE.

PART II.

1. Describe the method of finding the theoretical thermal efficiency.
2. Explain how there is any gain by using a steam jacket.
3. Explain the formula expressing the relation between pressure, volume and temperature of a perfect gas.
4. What is the mechanical efficiency of an engine?
5. What effect does speed have on the economy of an engine?
6. Explain the advantages and disadvantages of superheating.
7. If steam exhausts into a jet condenser, how much water will be required (theoretically) to condense 10 pounds of steam, if the entering water is at 55° F, the discharge at 118° F and the vacuum gage reads 13.7?
8. At what position of the crank is the maximum turning moment?
9. If the feed water is heated, is the economy of the engine increased?
10. What is the absolute temperature of 150° F?
11. Other things being equal, is a large engine more economical than a small one? Why?
12. Explain initial condensation.
13. Describe the action of heat on a body of water under atmospheric pressure.

14. Define the terms: saturated steam, superheated steam, wet steam and dry steam.

15. Name the properties found in the steam tables.

16. How does a condenser increase the power of an engine?

17. Explain how re-evaporation is possible.

18. How is the amount of steam used per hour found?

19. Explain with sketch how the crank effort is more nearly constant if there is more than one crank on the shaft.

20. In what two ways does compounding effect a saving of steam?

21. Give the formula expressing approximately the relation between pressure and volume of steam. What is it called?

22. Find the probable I. H. P. of a high-speed triple-expansion engine for a battle-ship. The engine runs at 150 revolutions; total ratio of expansion 12; initial pressure 145 pounds (gage); condenser vacuum 14 inches of mercury; the low-pressure cylinder is $72'' \times 36''$.

Ans. 2567 I. H. P.

NOTE.— Use card factor of .60 and atmospheric pressure 14.7 pounds.

23. What is the temperature of saturated steam corresponding to a pressure of 120 pounds (gage)?

24. What is the heat equivalent of work? How many foot-pounds of work equal one B. T. U.?

25. How many B. T. U. are required to furnish energy sufficient to raise 500 pounds 5,280 feet? How many pounds of coal will furnish this heat, assuming 6,800 B. T. U. per pound are available?

Ans. { 3,393 B. T. U.
{ $\frac{1}{2}$ pound (about).

26. How many cubic feet do 8 pounds of steam occupy when at 45 pounds absolute pressure?

27. How many B. T. U. are necessary to change 8 pounds of water at 320° F into steam at the corresponding temperature and pressure?

28. State Boyle's Law.

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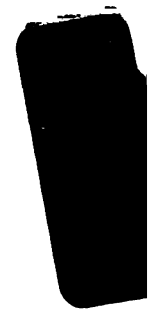

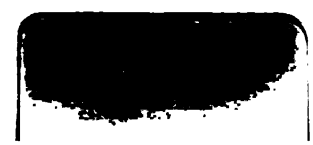

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